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CABINET

MINISTERIAL COMMITTEE ON ECONOMIC STRATEGY

FAST REACTOR POLICY

Memorandum by the Secretary of State for Energy

BACKGROUND

1. On 18 December 1980 E Committee agreed that, pending clarification of the scope for international collaboration, funding of the present UK fast reactor research and development should continue. The Committee wished in due course to see an evaluation of all the options for fast reactor policy, including those for international collaboration and for keeping a core team to act as informed purchaser of fast reactor technology when the UK needed it.

2. The fast reactor can improve the utilisation of uranium by 50 to 60 times and thus offers the world a vast potential source of energy for many hundreds of years.

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Spent fuel and depleted uranium from the UK's thermal programme is a potential indigenous resource of the same scale as our economically recoverable coal. The technical feasibility of releasing this potential is not in doubt. The fast reactor therefore has an important strategic attraction for the UK.

3. The current UK programme, which has cost £900m to date (£2500m in today's money), runs at some £110m per annum, and has established the UK as one of the world leaders. The present programme is centred on the operation of the Prototype Fast Reactor (PFR) and its associated fuel plant at Dounreay, and on design and development work for a full-scale Commercial Demonstration Fast Reactor (CDFR) whose construction could start, if required, as early as the late 80's.

4. The fast reactor could be of major strategic importance next century in providing a source of indigenous energy, diversity of supply and, in particular, an alternative resource to coal. But these benefits will be fully realised only if and when the fast reactor can be made economically competitive with the alternatives, including the Pressurised Water Reactor (PWR). At present it falls a long way short of this; the generating costs of CDFR are estimated to be about 1.4 times those of a PWR.

5. The economic viability of the fast reactor depends on bringing down its capital costs and a sustained rise in uranium prices. Forecast of its economics are very sensitive to assumptions made about both these factors which in turn are subject to great uncertainty, looking as far ahead as the first half of the next century. The fast reactor's intrinsically higher capital cost

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and novelty relative to the thermal reactor suggest that it will be prone to cost escalation. Moreover, earlier expectations of pressure on uranium supplies have been moderated by the drop in both forecasts of electricity demand and thermal building programmes throughout the world. However, at some stage a significant increase in uranium prices could well occur, although probably not this century.

6. Annex A is an economic analysis by the Atomic Energy Authority (AEA) with sensitivities based on a wide range of assumptions for capital costs and uranium prices specified by the Department. These sensitivities show that on a range of plausible assumptions the fast reactor could be an economic proposition in 2015, but that it is unlikely to become economic any earlier and, if uranium prices rise more slowly or capital costs prove optimistic the date could be very much later. Indeed it is possible that the fast reactor may never merit introduction solely on commercial grounds. The uncertainty about the basic assumptions and the consequent uncertainty about timescales inevitably casts doubt on the reliability of the AEA's analysis, but I do not believe the fast reactor could be economic within the next 30 years at the very earliest.

THE INTERNATIONAL ENVIRONMENT

7. It is clear from our discussions with France, the US, Germany and Japan that in all these countries there is an increasingly cautious view about the timescale for introduction of the fast reactor. The French, with their great dependence on imported fuel, and a more developed programme, have the greatest incentive to press ahead, but, even they are uncertain about the next steps after

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their demonstration reactor (Super Phenix) is completed in 1984/5. Although the Reagan Administration clearly attaches importance to the longer term potential of the fast reactor the US programme has been seriously hampered by continuing delays to the proposed Clinch River Breeder (equivalent of PFR), construction of which has still not been authorised.

OBJECTIVES OF FAST REACTOR POLICY

8. The UK's objective must be to have the ability to construct fast reactors as and when developments in the technology and or the uranium price make them competitive. This requires us either to develop alone, or in collaboration with others, the necessary fast reactor technology, or to have access to such technology through a licensing arrangement.

THE OPTIONS EXAMINED

9. Against this background my Department asked the AEA to advise on the costs and implications of the following options:

- I. rundown of fast reactor R&D; closure of PFR;
- II. maintenance of PFR in operation, but cut of 50% in the associated R&D programme;
- III. proceeding toward CDFR in collaboration with other countries;
- IV. proceeding independently to a CDFR.

These options, and variants on them, are described and discussed in Annex B.

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10. Options I and II would oblige us to rely on licensing the technology in due course. This is the least costly route; but this policy would carry the following risks:

- (i) the important strategic advantages of the fast reactor might be deferred if the technology were not available when we needed it and we had to rebuild the expertise necessary to make use of a licence;
- (ii) adapting to UK requirements would also cause delay in introduction;
- (iii) abandoning the fast reactor would reduce the UK's standing and influence in the world on nuclear matters, including non-proliferation;
- (iv) it could also cause damage to the international standing of British Nuclear Fuels Ltd (BNFL) whose commercial prospects are linked to investment in high technology areas such as the fast reactor fuel cycle;
- (v) UK industry would be poorly placed to supply specialised components.

11. Discussions with the Europeans and the US over the last 18 months (summarised in Annex C) have established that genuine collaboration with either party on a basis of equal partnership is possible, although further negotiations would be needed to

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confirm that satisfactory terms could be secured. Option III therefore appears viable and, because it offers savings and spreads risk compared with option IV, is to be preferred. The following assessment of the options therefore disregards option IV.

Option I : advantages

- immediate savings in public expenditure (£70m 1983/86)
- lowest overall costs over 20 years (£530m)
- no commitment to build CDFR

Option I : disadvantages

- reliance on licensing strategically and commercially risky
- Dounreay closure: loss of 2,000 jobs in Caithness (20% of the Caithness total) and further 2,000 jobs in England
- dissipates expertise and the value of technological achievements

Option II : advantages

- immediate savings in public expenditure (£60m 1983/6)
- intermediate cost over 20 years (£1145m)
- no commitment to built CDFR

Option II : disadvantages

- reliance on licensing strategically and commercially risky
- significant continuing expenditure with no clear objective

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- keeps open PFR and Dounreay at least temporarily
- only postpones decisions about Caithness problem
- loss of 1200 - 1500 jobs; around 20% in Caithness and the rest in England

Option III: advantages

- avoids risks of reliance on licensing
- makes good use of technological achievements
- could solve Caithness problem for long term

Option III : disadvantages

- costly: no short-term savings: 20 year expenditure around £3,000m although the benefits of an operating CDFR producing electricity for the grid could in some scenarios offset as much as £1300m of this cost

12. The advice of the AEA is set out in full in Annex B. Shorter statements of the AEA's position and that of the Central Electricity Generating Board (CEGB), South of Scotland Electricity Board (SSEB), BNFL and the National Nuclear Corporation (NNC) are at Annex D. The AEA believe the fast reactor will be economic around 2010/20, and recommend option III. They consider that there is little scope for international collaboration with a programme the size of option II or smaller, and that options intermediate between I and II provide poor value for money. The others are more cautious about timescales but all favour option III and do not rule out

modest financial participation. They are more optimistic than the AEA about the possibilities for a programme of the size of option II, provided its objectives are defined to meet the more extended timescales now envisaged, and the need to explore new concepts. The NNC in particular believe that the possibilities for departures from the present basic design concept should be examined as the most promising way to achieve an early reduction in generating costs.

CONCLUSIONS

13. The analysis in Annex A strongly suggests that, while fast reactors may be economic as early as 2015, this is the earliest likely date and it could be very much later. I conclude, therefore, that the case for a major programme aimed at the development of our own CDFR in the relatively near future is weak and the AEA's option III too expensive. But I also believe that the risks of running our programme down to a minimum are too great. Instead, I propose that we should ask the industry to devise, if possible in collaboration with other interested countries, a significantly less expensive programme which takes advantage of the extended time which now seems likely to be available. That programme should not be based on the assumption that demonstration fast reactors would be built in the near or even medium term, but should instead seek to refine current design concepts and to proceed with a more limited R&D programme aimed at reducing the capital costs of fast reactors and improving the economics of the fast reactor cycle. Such a course could give us a continuing role in fast reactor development, capitalise on our established technological position, reduce the extreme risk of relying on licensing (since we would

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continue to be involved in collaborative development work with the others) and avoid many of the problems associated with a complete rundown of the programme. There would be expressions of disappointment from overseas, and possibly some suggestions that the UK was once again in danger of failing to exploit a high technology which it had, at great cost, pioneered. But, because others involved overseas are beginning to make more cautious assessments similar to our own, our reasons for such a change should be understood and respected; and we might expect some positive support for a more limited programme, extended in time, as the basis for collaboration.

14. In seeking to run the programme down to an acceptable level of expenditure a major constraint is the technical need as a focus for any worthwhile programme - and in my judgement strategic and political requirement - to keep the Dounreay site open. Operation of PFR and its associated plants presently cost some £47m, with the R&D programme running at around £60m. By 1986/7, the earliest that we can hope to see the full effect of a decision to cutback the programme, PFR costs should be down to £35m pa. I consider that a reduction of the Authority's R&D expenditure to £25m pa, making a total cost of £60m pa in the late eighties could provide a satisfactory basis for a properly focussed programme.

15 While £60m is the right order of magnitude for the overall resource devoted to fast reactor work, it is essential for the Boards, as ultimate customers, and for the industry as a whole, to have a direct financial stake in the programme and a say in its formulation and direction. We should therefore insist on the

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participation by the Generating Boards, BNFL and NNC, in the formulation of advice to the Government and on some financial contribution by them to the programme.

16. Sir Peter Hirsch has made it clear that he would strongly prefer a minimum programme of at least £70m per annum; but I have explored informally with him the possibility of a programme costing only £60m. I believe he would use his best endeavours to devise such a programme. I would expect him to be able to carry his board. However, a complete withdrawal from the fast reactor (option I) or any route leading only to licensing, would probably lead to resignations. Sir Walter Marshall will be disappointed with any winding down of the programme, and might say so publicly.

17. I therefore propose, subject to the Committee's views to put the following proposition formally to the AEA Board.

- (i) the existing programme is cut, so that the cost to the vote is reduced from £110m a year to £60m as soon as possible but certainly by the late eighties. I would tell them that this is the highest insurance premium the Government is prepared to pay to retain access to the technology through participation in development;
- (ii) the Generating Boards, NNC and BNFL should be asked to contribute to the programme and to participate in it;

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- (iii) there would be no intention to proceed to a CDFR in the foreseeable future;
- (iv) the programme should be phased over a longer timescale and be directed towards refining and improving fast reactor design concepts; and improving the economics;
- (v) I should receive a recommendation based upon consultation with the industry which set out:
 - (a) how the money would be spent
 - (b) with what objectives, and over what timescales
 - (c) how much would be contributed by the industry
 - (d) advice on the viability of such a programme, and whether it represented reasonable value for money
 - (e) the scope for international co-operation (as a way of making better use of our expenditure rather than achieving further savings)

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18. On the basis of the Board's advice, I would decide whether to recommend the programme to colleagues or to propose more radical changes along the lines of option I.

PUBLIC STATEMENT

19. I am committed to making a public statement on fast reactor policy this coming session, and as soon as Parliament reassembles there will be pressure for an early statement. Potential international partners will also expect to know how we intend to proceed. I therefore propose to make a statement which makes clear that we are slowing down the fast reactor development programme with no intention to build a CDFR in the near future; but that detailed decisions on the balance and direction of the programme will be taken in the light of further advice from the industry and of further discussions with potential international partners.

RECOMMENDATIONS

20. I therefore invite the Committee
- (i) to agree that there is no basis for proceeding with options III or IV;
 - (ii) to authorise me to seek further advice from the industry based on a reduced budget as set out in paragraph 17;
 - (iii) to authorise me to make a statement along the lines set out in paragraph 19.

N.L.

ECONOMIC ANALYSIS AND URANIUM SUPPLY/PRICE PROJECTIONS

The two papers attached to this annex have been prepared by the Atomic Energy Authority.

2. The Economic Analysis (appendix A1) sets out in Section II the Authority's evaluation of the likely generating costs of the fast reactor. These are summarised in figures 1 and 2, and support the Authority's belief that the fast reactor is likely to be economic in the decade 2010-2020.
3. The Department examined the underlying assumptions and methodology in this analysis; and concluded that a wider range of capital cost and uranium price assumptions needed to be considered, and that a more sophisticated analysis was needed based on an assumed series of commercial fast reactors, and of the costs incurred in reaching the point where such a series could be ordered. Such an analysis should then be used to test the sensitivity of the economics to variations in assumptions, and to examine the financial implications of a delay in introduction of fast reactors arising from difficulties in obtaining and adapting a licence. Sections III and IV of appendix A1 were prepared to meet this specification. For the sake of simplicity this analysis concentrated on options I and III.
4. The analysis shows that the range of uncertainty is extremely wide, and that comparisons between the cases can produce very large differences in benefits arising from very small differences in overall capital costs. It further shows that introduction of the fast reactor in 2015 could be an economic proposition on a wide range of plausible assumptions about capital costs and uranium prices, but is unlikely to be economic much earlier; and if uranium prices rise very slowly or capital costs prove optimistic the date could be pursued much later. The paper also shows that while the costs of pursuing option III are well defined and limited, the penalties of a delay in our ability to deploy fast reactors in the period from 2015 to 2035 could range in an extreme case up to many thousands of millions of pounds in present money terms, while the penalties of proceeding with the CDFR prematurely are much more limited. These conclusions are illustrated in figures 5 and 6 of appendix A1 for a 30 year programme of fast reactors. However the uncertainty about the basic assumptions, and the consequential uncertainty about timescales and benefits are so great that not much reliance can be placed on them, beyond the conclusion that fast reactors are unlikely to be needed before 2015.
5. The Uranium supply/price projections (Appendix A2) explains the Authority's methodology in arriving at their forecasts of uranium prices, and sets out the forecasts in figure 5.

THE ECONOMICS OF FAST REACTORSI INTRODUCTION

The considerable impacts arising from fast reactors will extend well beyond their direct effect on UK electricity generating costs, although it is on this aspect that attention tends to focus. This note summarises these other impacts and looks at the prospects for generation costs. Additionally, development costs are compared with generating cost savings as one input to an evaluation of research, development and demonstration expenditure. Finally, the additional benefits from Option III over Option I are compared with their expected cost difference.

II COMPARATIVE GENERATING COSTS

This section examines the prospects in the early decades for generating cost savings from fast reactors. Development costs are excluded as we are only considering the factors likely to influence the future decision to build commercial fast reactors.

Expected generating costs have been estimated under a wide range of capital and fuel cost assumptions. These are described in Appendix 3.1. The results are shown in Figures 1 and 2. Discounted mean lifetime generating costs of fast reactors are compared with coal and thermal reactors. Costs for each type of station are shown as areas rather than discrete lines to indicate the range of possible outcomes. For coal stations the variations are due to differences in future price profiles as indicated. For AGR and PWR the range shows the effect of $\pm 10\%$ uncertainty in capital costs. The fast reactors' cost range includes variations in capital and reprocessing charges resulting from possible foreign collaboration and variations due to alternative fuel burn-up assumptions. The 1995 to 2000 range illustrate CDFR costs, and the later range is for typical commercial fast reactors. The AEA's thermal reactor figures are within a few per cent of the figures in the CEEGB's PWR Inquiry Statement of Case, although the input assumptions differ slightly. AEA coal price assumptions of 1%, 2% and 3% pa followed by 2% post 2000 span the CEEGB's central assumption of 1.9% pa to 2000 followed by 1.6% pa.

In comparing the costs of fast and thermal reactors in the early decades of the next century, there are major uncertainties on capital and fuel cycle costs, performance and uranium prices. In the absence of major market perturbations, it is the Authority's view that thermal and fast reactor costs are likely to breakeven for stations commissioned between 2010 and 2020, although it could possibly be earlier or later. This view is shared by CEEGB. Throughout the early decades of the next century, the costs of fast and thermal reactor electricity will be very similar, in view of the many uncertainties. Beyond this period fast reactors should have a clear competitive advantage.

These benefits for a 30 year programme of fast reactors replacing PWRs are shown in Figure 3.

Present worth benefits for 1.25 GW pa could range from zero (no cost difference or no fast reactor deployment) to many £1,000Ms. They seem likely to be several £1,000Ms. This figure re-emphasizes the point that the precise magnitude of fast reactor benefits is highly uncertain and depends on assumptions on the state of certain world market until the middle of the next century.

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At the Department of Energy's request we have presented results, shown in Figure 4, for a wider range of fast reactor capital costs, for an even lower uranium price profile, and for a time invariant fast reactor fuel reprocessing cost, which rises in real terms. We doubt the rationale for these variants and comment on them in Appendix 3.2.

Tables 1 and 2 show the dramatic increase in fast reactor benefits when compared to AGRs and coal-fired stations.

The date when fast reactors will breakeven with thermal reactors is inevitably uncertain. As the shape of the generating cost curves in Figures 1 and 2 shows, for many years we expect costs to be very similar. However, the precise breakeven date will be affected by many factors whose sensitivity is shown in Table 3. This date is most sensitive to changes in uranium prices. A $\pm 50\%$ change in uranium prices could change the breakeven date by around 7 and 14 years in the low and high uranium price profiles respectively. Capital costs are a further important factor although many reasons for cost escalation may affect both thermal and fast reactors, thereby reducing the impact on the breakeven date.

III DEVELOPMENT COSTS AND GENERATING COST SAVINGS

Development of fast reactor technology to the point of commercial ordering will involve large expenditures. Total present worth development costs to the point of commissioning series ordered CFRs have been estimated for two options: Option I costs could range from £750M to £1,100M and Option III could be around £1,250M. The basis for these figures is described in Appendix 3.3. In evaluating R, D and D expenditure one factor, among many we must consider, is - how do these costs compare with the possible generating cost savings fast reactors might provide?

This comparison is shown for AEA and Department of Energy Assumptions in Figures 5 and 6 respectively, relative to PWRs. (Comparisons with all other stations will increase fast reactor benefits considerably.) These figures show the following important economic aspects of fast reactor development:

- (i) at high uranium prices, benefits exceed development costs by several £1,000M present worth;
- (ii) at medium uranium prices, benefits easily cover on AEA assumptions or just cover development costs on D.Energy assumptions;
- (iii) at low uranium prices, benefits are of the same magnitude as development costs (AEA);
 - benefits are below development costs (D.En);
- (iv) large losses would be avoided by not deploying fast reactors in unfavourable economic circumstances.

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IV COMPARISON OF OPTIONS I AND III

The principal difference between the benefits of Options I and III is related to timing. Option I leaves the UK unable to commission series fast reactors much before 2035, and hence benefits cannot be obtained before this date. Pursuit of Option I leaves the UK exposed to the risk of prolonged dependence on expensive uranium and thermal reactors. Expressing this more positively, the possibility of fast reactor generating cost savings up to 2035 could be obtained at the small cost difference (£150M to 500M) between Options I and III. This differential benefit could range from zero to many £1,000M present worth as shown in Figures 7 and 8, and would be beneficial at medium and high uranium prices.

V THE WIDER BENEFITS OF FAST REACTORS

The preceding analysis has concentrated on the direct economic benefits of fast reactors and ignored many important wider benefits. As fast reactor net fuel consumption is trivial (about 1 tonne of depleted uranium per 1000 MW station per year) each reactor will be an assured energy source not susceptible to disruption by extra-national events. With a significant fast reactor generating component, and with associated plants for recycling plutonium into new fuel, the UK would become virtually self-sufficient in fuel for base-load electricity, at future costs comparable to today's thermal reactor technology. The UK already holds stocks of depleted uranium (20,000 tonnes) which represent an indigenous source comparable in scale to UK economically recoverable coal resources (45,000 million tonnes). In contrast, PWRs can extract only a small part of the energy in uranium (about 1%) and each reactor will require some 6,000 tonnes of imported uranium over its life at a cost of £250M per reactor, which is likely to rise considerably.

On an international basis, fast reactors give potential access to all the energy locked in the world's uranium resources, which is at least 1,000 times larger than present world energy consumption (on a primary energy basis). International development and deployment of fast reactors will act as a constraint on the price of uranium and other fuels post-2000 when the costs of fossil fuels are expected to rise rapidly and third world countries' demands are growing.

Energy is also the key to the efficient exploitation and ultimate costs of other resources, e.g. food production, water supply, transport and mineral extraction. Lower energy costs increase the effective resource base. Increasing and diversifying the energy resource base and holding costs down should permit faster economic growth than would otherwise be practicable and, additionally, by removing one potential source of world economic and political instability, it could remove or reduce the adverse effects of price and supply shocks, similar to those which have persisted since the early 1970s.

The industries in countries that take part in fast reactor development will have large markets open to them, not only for specialised components but also for the related products that inevitably follow from major technological advances.

These wide ranging effects cannot be expressed readily in monetary value to the UK. They are very important elements in a wider context of fast reactor benefits, and have been omitted in Sections II to IV.

APPENDIX 3.1

Assumptions Underlying Generating Cost Comparisons

Two methods have been used for cost comparisons. The first 'single station costs' looks at each station independently, the second considers each station plus its impact on other stations in the generating system. This is known as the 'net effective cost' method.

(1) Single Station Costs

Capital costs for fast reactors are based on NNC estimates while those for coal-fired and thermal reactor stations are based on CEGB and NNC estimates, all with appropriate allowances for customers on-costs, and interest during construction. CEGB practice has been followed by introducing a further contingency allowance which in our case also contains an additional 1% pa real cost escalation factor for stations completed post 1989, which CEGB do not include.

This approach is adopted so that calculations are comparable to those conducted by the Generating Boards for investment appraisal purposes. For later power stations (post Sizewell or post CDFR) capital cost reductions are introduced to allow for replication and the adoption of twin reactor sites. Technology is assumed throughout to be broadly as at present with no radical design changes.

There is inevitably uncertainty surrounding future capital costs including those of coal stations and thermal reactors, and this is catered for in both our contingency allowance and designer's contingency allowances built into the basic capital cost figures; ie. if all went to plan the stations would be some 10% or 20% cheaper than the "best estimate" figures. Equally, it can be argued that unforeseen developments may force costs higher. Even though the fast reactor, being at an earlier stage of development, may appear more susceptible to such change, over 50% of its cost arises from conventional components and concrete and steel and the whole design has been very carefully costed. Furthermore, its inherently good safety characteristics give grounds for expecting it to be less subject to tightening safety requirements than its thermal counterparts. On this basis, after consultation with NNC, a sensitivity range of $\pm 10\%$ has been used for both fast reactors and thermal reactors to illustrate the effects of uncertainty.

The costs of generation from coal-fired stations have been calculated for 3 coal price profiles rising at 1%, 2% and 3% (followed after 2000 by 2%) per annum real increases. The CEGB's central Sizewell scenario C is based on 1.9% to 2000 followed by 1.6% pa.

Thermal reactor nuclear fuel cycle costs are based on low and high uranium price profiles developed by AEA. These are closely similar to scenarios recently published by the CEGB in the Sizewell Case, and appear to be in line with US views that have been indicated to us informally. Post 2010 our low projections are significantly below those presented by CEGB (see separate Annex, Figure 5).

Separative work costs and fuel fabrication costs for thermal reactors are based on BNFL costs and CEGB cost estimates developed for Sizewell. Although there are some differences depending on whether one adopts UK or international market figures the effects of these on generating costs are small - in the region of 1%.

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There are also uncertainties about future thermal fuel reprocessing costs. These arise from uncertainties about plant costs and throughput, the methods which can be adopted for costing and from assumptions about policies for spent fuel storage. For purposes of illustration, AGR fuel is assumed to be reprocessed after 3-5 years assuming commercial plant costs based on discussions with BNFL whilst PWR fuel is reprocessed after prolonged storage. These represent bounding cases in which the lower cost bound is not sensitive to changes in the costing methodology.

It is assumed it will be necessary to demonstrate reprocessing of CDFR fuel immediately, and that in the worst case we will have to cater for CDFR throughout its 25 year life, if a commercial programme is delayed. The cheapest option would be to build a restricted specification plant of 50 tpa throughput costing around £320M to construct and £10M pa to operate. The plant would be provided with sufficient waste management facilities, including vitrification of HAL, to last 25 years. It would not be necessary to provide the demonstration plant with the degree of redundancy required in a commercial plant to ensure high availability. The operating cost of £10M pa allows for sufficient refurbishing to ensure plant operation for 25 years. During this period, unit reprocessing costs could be reduced by reprocessing fuel from a foreign fast reactor as part of a collaborative programme, and the cost effect of this has been examined (see Figs. 1 and 2).

Large commercial size plants will cater for a series of CFRs. These plants will be built to the commercial requirements of BNFL to ensure high availability and full radioactive waste management. Furthermore, unlike the demonstration plant which will be a nationally funded project not required to earn a return on capital invested, reprocessing charges will be based on commercial practice. Initially these are expected to be around twice those for thermal oxide fuel per unit weight of heavy atoms subsequently falling to about the same value per unit weight as for thermal oxide fuel as plant throughput increases. However, even if these last gains were not realised the fast reactor generating costs shown in Figs 1 and 2 would not be raised by more than about 0.05 p/kWh (subsequent to 2015).

New fuel for the initial core of CDFR together with that required for the first 10 years' operation, would be fabricated in a small dedicated plant of 20 tpa throughput having a capital cost of £80M and an operating charge of £20M per annum. To cover the "go-it-alone" case with a delayed commercial programme, CDFR fuel has been costed with high fabrication prices arising from the use of a small demonstration plant throughout its lifetime. For a commercial size plant, core fuel fabrication prices would come down to 10 times thermal reactor fuel, falling to around 6 times as throughput increased. Again, the sensitivity of the generating cost to these latter reductions would be small.

The figures are based on a 35 years life for PWR, 25 years for AGR for consistency with CEBG Sizewell assumptions. The unit generating costs for the lowest thermal reactor case would be increased by 0.2p/kWh if a 25 year life were taken for PWR. A 35 year life is also considered feasible for fast reactors and is used (except for CDFR taken as 25 years). Use of 25 years figures (coal and nuclear) are based on a 70% mean lifetime load factor, which can be viewed as a target figure for CDFR, and a reasonable figure for later commercial fast reactors. A lower figure might be considered appropriate for PWR. If 64% were taken, in line with Sizewell, its unit generating costs would be raised by about 0.1 p/kWh. If CDFR only achieved an average 60% load factor its unit costs would rise by about 0.3 to 0.4 p/kWh. (CEBG expect later PWRs to move towards 70% load factor and include this in their background assumption).

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In the results presented in Figs. 1 and 2, reprocessing costs are charged to thermal reactors and credit is given for the uranium in spent fuel, although no value is ascribed to plutonium. (The reprocessing component of PWR generating costs with deferred reprocessing amounts to only 0.06 p/kWh, which may be an underestimate for post Sizewell PWRs with shorter deferment periods). Similarly, no charge or credit has been made for plutonium used and produced in fast reactors. This is acceptable in the case of CDFR as sufficient plutonium will be available from reprocessing Magnox and early commercial AGR fuel for its initial inventory and, indeed, for its lifetime requirements if no further fast reactors were to be commissioned and no demonstration of the complete fast reactor cycle was required.

For later fast reactors, it might be argued that fast reactors should bear the net costs of reprocessing ie. reprocessing charges less the value of recovered uranium plus savings in fuel storage costs. However, fast reactors should also be credited with a value for the excess plutonium produced during their life and in their final cores. In practice, we cannot be precise about the impact of delayed reprocessing on fast and thermal reactor costs, but it might slightly delay the point in Figures 1 and 2 at which fast reactors become cheaper than thermal reactors.

Finally, it must be noted that single station generating cost comparisons are not wholly comprehensive in assessing the consequences of following alternative reactor and reprocessing strategies. No proper assessment can be made of the production and use of plutonium by changes in parameters such as lead/delay times, burn-up and fuel geometry. These aspects are better assessed by considering a whole generating system to determine the net effective cost of introducing a new station. As remarked above, this exercise has been performed and gives similar conclusions.

(ii) Differential Net Effective Cost of CDFR

The calculation of the cost of introducing a new station requires assumptions about the numbers and types of plant in operation, future demand growth and types of plant to be installed to meet this growth.

The differential cost of introducing CDFR or a new coal station in 1995 in place of a PWR have been calculated making the following programme assumptions:

- (a) Total generating capacity in the year 2000 is 60 GWe rising to 100 GWe in 2040.
- (b) Nuclear capacity in 2000 is 16 GWe with 80% of post-2000 new capacity being nuclear.
- (c) Coal prices and uranium prices follow low profiles, ie. 1% pa for coal and 3% pa for uranium falling to 2% pa post-2000.

On this basis the differential systems cost for either a new coal station or CDFR commissioned in 1995 is the same at +£60/kW per year. (For the purposes of this calculation CDFR and PWR were assumed to have 25 year amortisation periods - a longer period would increase the differential for coal and reduce it for CDFR).

If, as is widely expected, coal prices rise more rapidly than 1% pa in real terms (CEGB central assumptions are nearer to 2% pa, para. 19) the CDFR would yield significant savings compared with coal. Higher uranium price rises would reduce the systems net effective cost for CDFR.

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The CDFR costs used in this calculation employ central estimates of capital cost and assume a small fully utilised shared reprocessing plant in the early years, together with the small fabrication plant.

At the time when CFR and PWR breakeven on single station levelised costs, there will be a small negative cost differential in CFRs favour if it is commissioned in place of a PWR, due to the lower CFR fuel cycle costs and its consequent higher place in merit order operation.

APPENDIX 3.2

Sensitivity Assumptions on Fast Reactor Benefits

(i) Capital Cost.

Of a total £2310M commercial cost for CDFR (£1850/kw) only £550M, or less than 25%, is due to the direct cost of the reactor plant and further £500M is included for contingency and real cost escalation. The component cost estimates are based on many years of design and development, and recent work comparison with the costs of corresponding components in Heysham II. The U.K. technology and industrial experience behind fast reactors is far greater than has been the case for any thermal reactor system when it was ordered commercially, and even the prototype PFR (and the French Phenix) were built within 15% of the estimated cost.

For these reasons a $\pm 10\%$ uncertainty on total capital (in addition to contingency and escalation allowance) is seen as reasonable by NNC and the AEA, adding as it does £230M to the existing contingency of £500M.

Department of Energy have asked for a larger range $+30\%$ to -15% to be covered. The upper end corresponds to a total over-run on base estimate of £1190M which looks excessive in relation to the small nuclear component cost (£550M), much of which is not dissimilar to a thermal reactor. Certainly if such rises take place it is hard to see why they should not affect thermal plant similarly, so in terms of differential escalation the figure seems unrealistically high.

(ii) Uranium Prices.

Uranium prices are the subject of a separate note. It is always possible to postulate quite arbitrarily any alternative figure and equally difficult to dispute small changes such as the 75% of the CEGB low price profile requested by the Department of Energy. AEA scenarios though close to the CEGB median already have low cost profiles which are 75% or less of CEGB's from the first decade of the next century. An additional still lower range of 75% of AEA's low has been included in the Table 2, but is regarded as too low by the AEA.

(iii) Fast Reactor Fuel Costs.

The central assumptions employed are based on BNFL/AEA experience of commercial plant and allow for learning and scale up though no radical changes in technology. They benefit from the lessons of Magnox reprocessing plant refurbishment and THORP costing and the need for stringent radiological protection and material safeguards and security. The programme and time invariant figures included at the Department of Energy's request do not appear to take account of any of these factors and are not regarded as a credible alternative.

APPENDIX 3.3

Development Cost Assumptions

(i) Option I

We assume that a decision to pursue Option I implies a judgement that series fast reactors will not be needed before 2035, and that the Dounreay facilities will have been run down to stage 2 decommissioning before the policy reversal occurs. In addition to the Option I costs from the "Options Paper" (viz. £520M)* there will be the costs for constructing the CFR (taken as £200M less than CFR (1)**), the initial downpayment on a licence on the reactor design (2) (taken as £100-200M) and the initial cost of a licence on reactor fuel manufacture (also taken as £100-200M) (3). This initial "entry fee" would be supplemented by a levy on each reactor and on the fuel cycle which could be in the region of 5-10%. This would be broadly equivalent to an additional capital sum of £500M - £3500M discounted to the commissioning date of the first fast reactor (4). (The fuel cycle royalty is treated later under benefits).

Additionally new laboratories and test facilities would be needed to replace those now in existence. This could cost from £100-500M depending on the scale of support desired and the standards prevailing in the future (5). Operating costs for these laboratories, mainly labour, could add a further £20M p.a. (6).

Under option I licensing will have to await the availability of a fully commercial fast reactor and this is not likely to exist, even in France, before 2015. The need for an inquiry, a lead station, etc., then makes the earliest date for series ordering around 2035 (see Appendix 2). Licensing at a less developed stage would be practicable with Option II.

If the new lead CFR costs are incurred from 2015 on and the initial licence fees and UK facility costs are incurred in 2015 with support labour also in post from 2015 on, then the present worth cost of Option I (1982 base date) becomes £700M to £1000M, assuming a licence to be available, and a programme in the range of 0.5 to 2GW from 2035. Of this, £400M*** is the unavoidable cost and the remainder is incurred through re-establishing the option. This excludes the regional impacts of a Dounreay run down, and the items listed in para. 44(ii), which could add a further £50M to £100M to the short-term and total costs. It also excludes re-establishment costs of the type listed in para. 44 (ix) which affect only the longer term and total.

The alternative of a UK crash programme made necessary by the failure to negotiate a licence would lie towards the upper end of this range and would tend to constrain licence fees to this level, provided the scale of the programme were appreciated in advance.

* Excluding the already committed 1982/83 expenditure of £108M.
 ** For Footnotes on 1-6 see the end of this Appendix.
 *** Excludes £108M already committed for 1982/3.

(ii) Option III

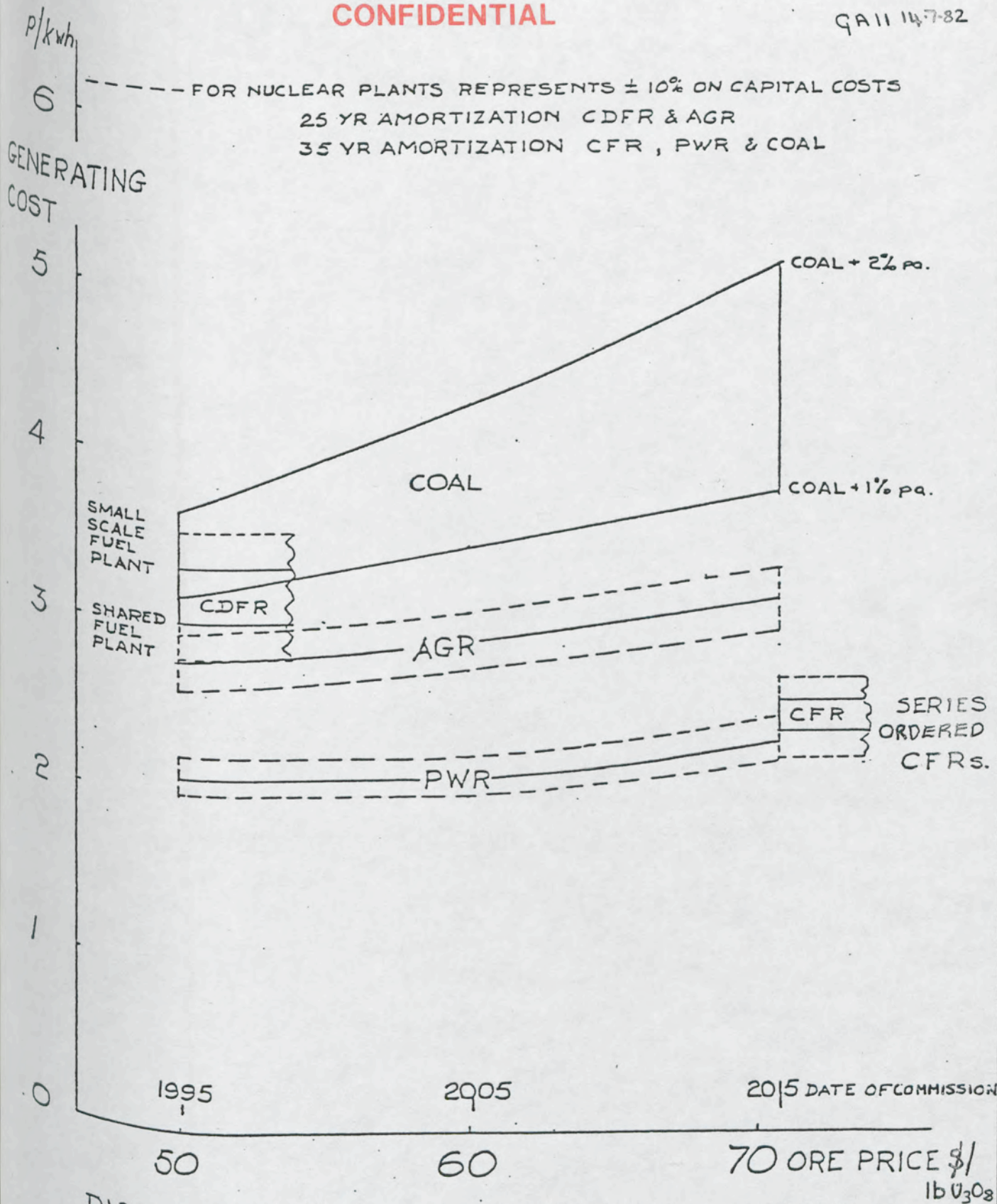
If Option III were pursued then the discounted total costs, including R & D declining to £20M p.a. by 2000 would be £1100M*** based on the figures in the "Options Paper". For strict comparability a sum should be added for decommissioning PFR, although this will be much less than in the Option I case since the Dounreay site is assumed to be fully operational. Taking these costs as 33% of the option I costs and starting the PFR decommissioning from the year 2000, gives an added discounted cost of £50M. Some post 2000 back-up support will also be needed and this is taken as £20M p.a., for comparability with option I. The total present worth cost of option III until 2015 on this basis is £1240M. Any R&D or back-up support after series ordered reactors are commissioned is assumed to be in support of later benefits and excluded for both this and the option I case.

(iii) Option II

The short term unavoidable costs of option II on the same basis amount to some £650M present worth with reduced redundancy costs compared with option I offsetting the PFR operating costs. The longer term costs will depend on decisions in the 1990s. If the programme is curtailed additional run down costs will be incurred. If not, then licensing or further development costs will arise, the level of which will depend on timing. The total cost could lie between that of options I and III or even greatly exceed option III. Pursuit of the option will allow earlier fast reactor deployment than allowed by option I (though not as early as allowed by Option III).

Footnotes

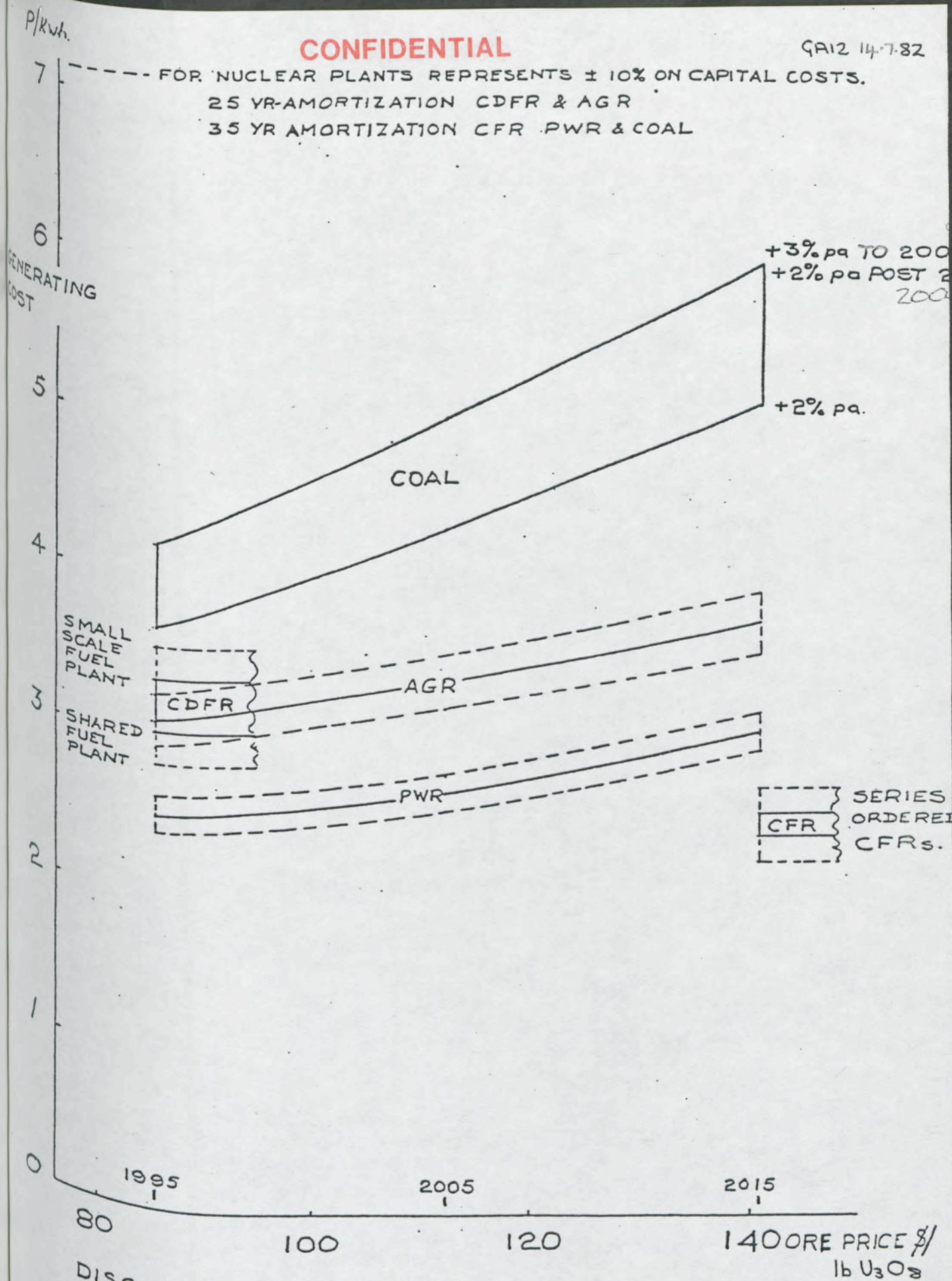
1. The first UK fast reactor would benefit from overseas "learning" but would also incur initial UK industrial learning and tooling-up costs. A cost between CDFR and UK series ordered reactors is therefore considered appropriate.
2. The licensing situation is complex and very different from the PWR situation. In the first place several separate licences will be needed to cover design and manufacturing aspects of both reactor and fuel. The likely monopoly position of the licensor will encourage him to press for high royalties related to electrical output or fuel throughput, particularly since the UK would become a competitor in the supply of services. The licensor would also be aware of the high costs to the UK of re-entering the field if option I had been followed.
3. These figures are based on past French requests under circumstances where the UK had a strong bargaining position.
4. At £75-150M per reactor for 1 reactor per year over 20 years discounted to the year of commissioning the first series ordered reactor this amounts to £900M to £1800M. For 0.5 to 2 reactors per year the range becomes £500M to £3500M. They are taken to cover manufacturing as well as system design royalties.
5. The new metallurgical laboratory at AWRE is costing £80M and a small extension to B220 at Harwell, with pre-existing ventilation, etc. is costing £10M.
6. Based on long term support level costs given against option III.



DISCOUNTED AVERAGE GENERATING COSTS VS.
DISCOUNTED AVERAGE ORE PRICE AND/OR
DATE OF COMMISSIONING (70% LOAD FACTOR)
(LOW RATE OF FUEL PRICE INCREASES) FIG 1

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DISCOUNTED AVERAGE GENERATING COSTS vs
DISCOUNTED AVERAGE ORE PRICE AND/OR
DATE OF COMMISSIONING (70% LOAD FACTOR)
(HIGH RATE OF FUEL PRICE INCREASES)

FIG. 2

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FIGURE 3 BENEFITS OF A FAST REACTOR PROGRAMME
RELATIVE TO PWRs. 30 YEARS AT 1.25 GWpa.
(AEA ASSUMPTIONS)

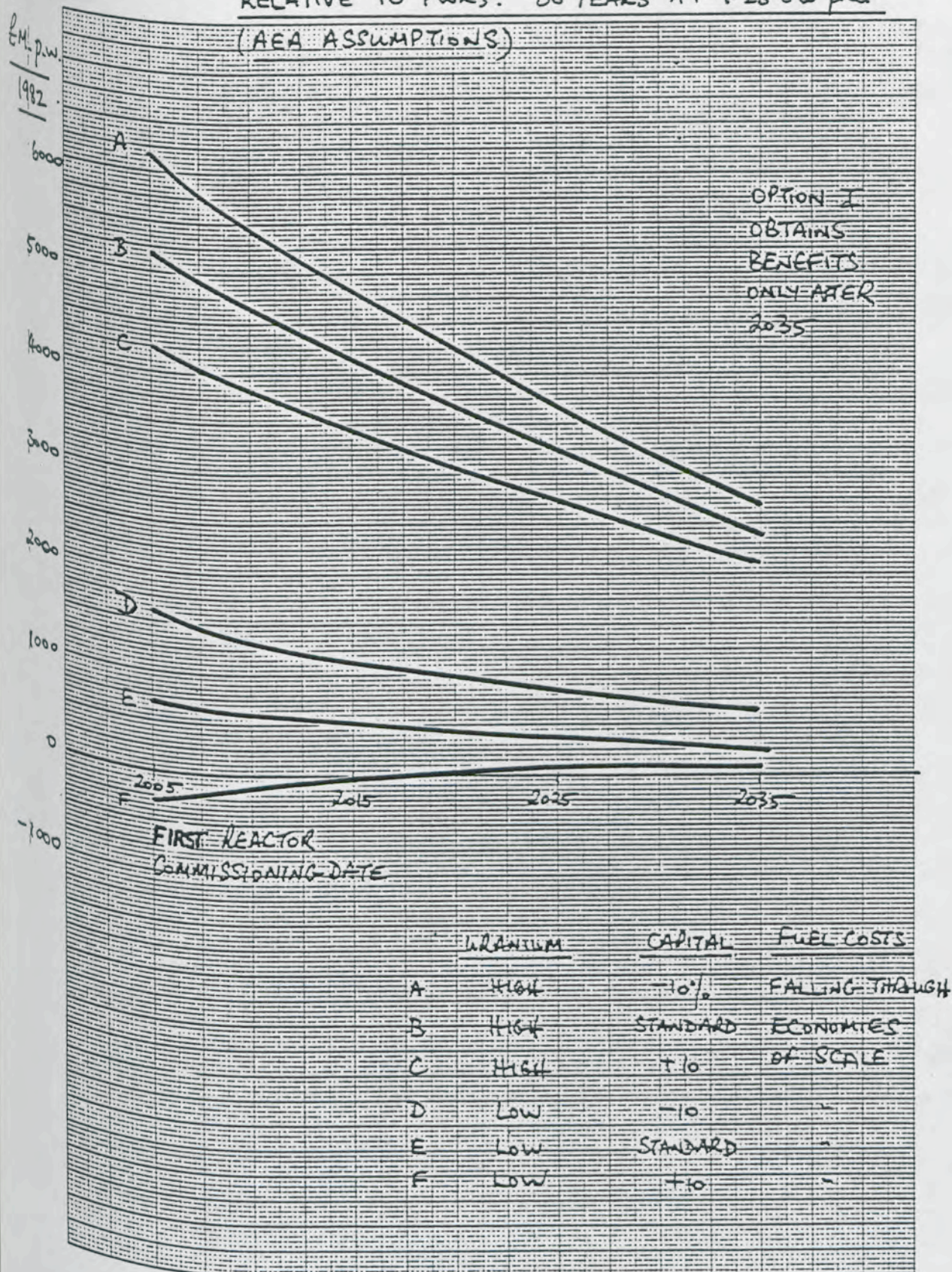


FIGURE 4

BENEFITS OF A FAST REACTOR PROGRAMME
RELATIVE TO PWRs. 30 YEARS AT 1.25GWp.e
(D.ENERGY ASSUMPTIONS)

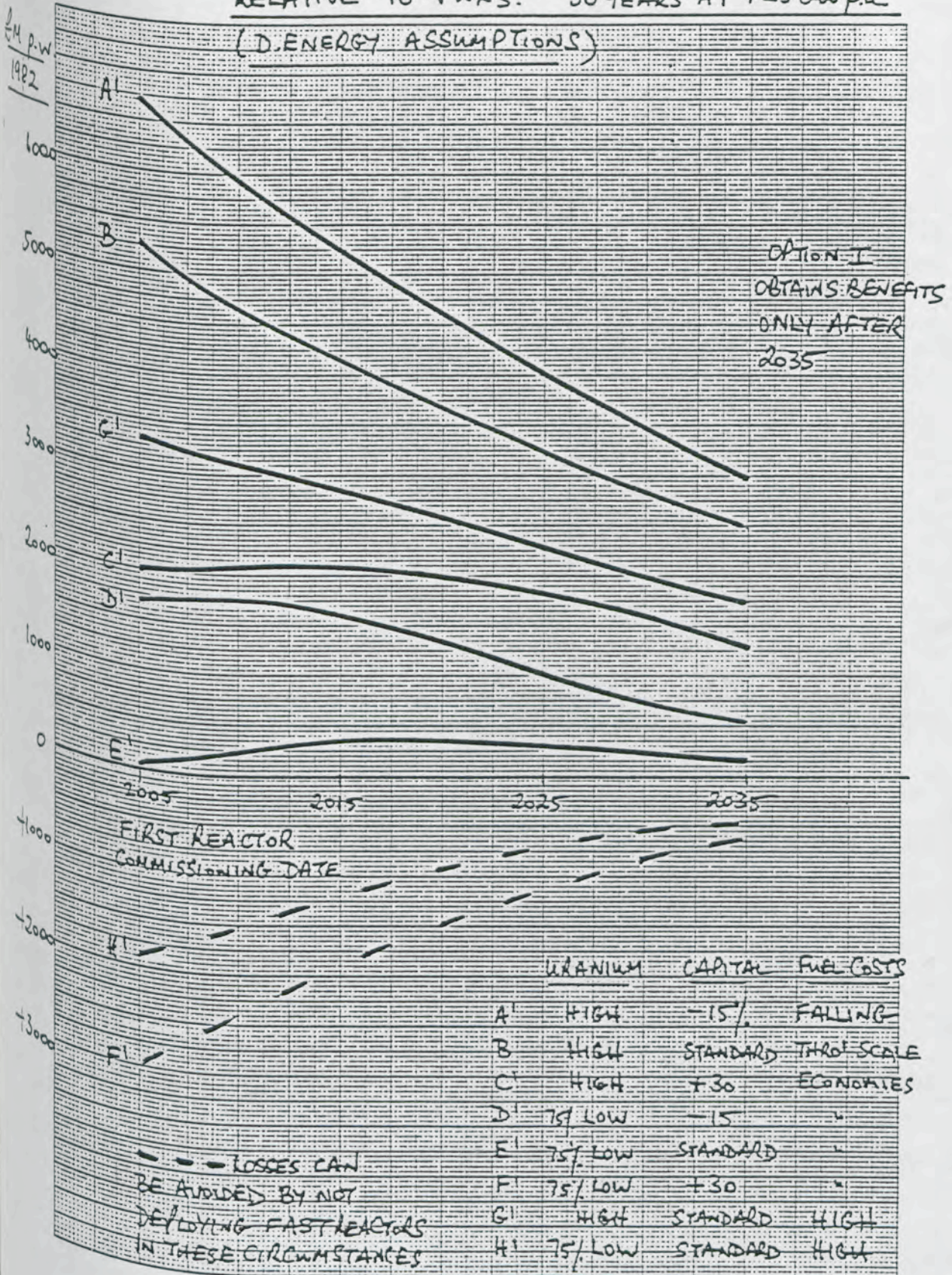


FIGURE 5 BENEFITS AND DEVELOPMENT COSTS OF A FAST REACTOR PROGRAMME
RELATIVE TO AWRs. 30 YEARS AT 1.25 GW p.a.
(AEA ASSUMPTIONS)

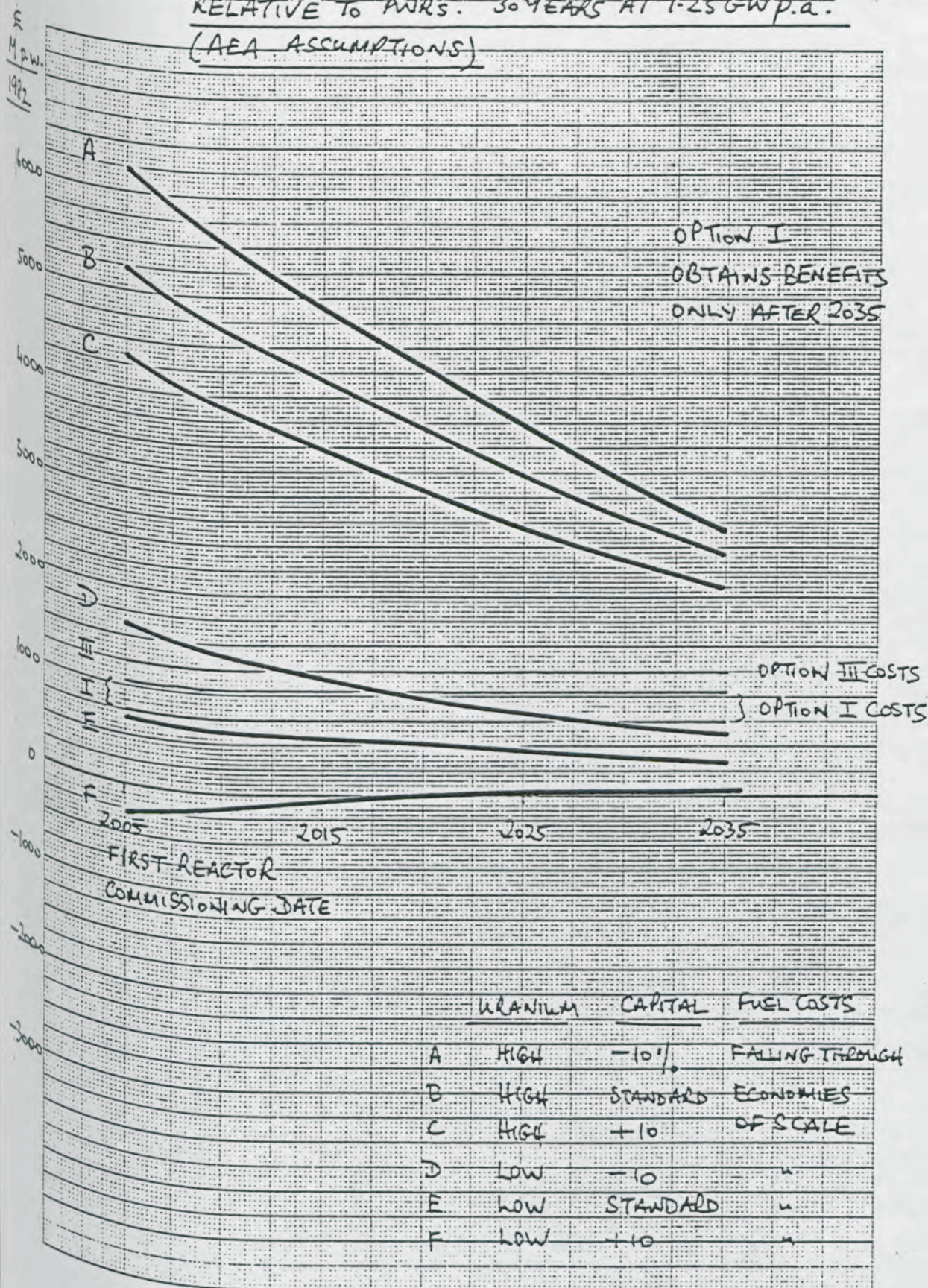


FIGURE 6 BENEFITS AND DEVELOPMENT COSTS OF A FAST REACTOR PROGRAMME
RELATIVE TO PWRs. 30 YEARS AT 1.25 GW p.a.
(D-ENERGY ASSUMPTIONS)

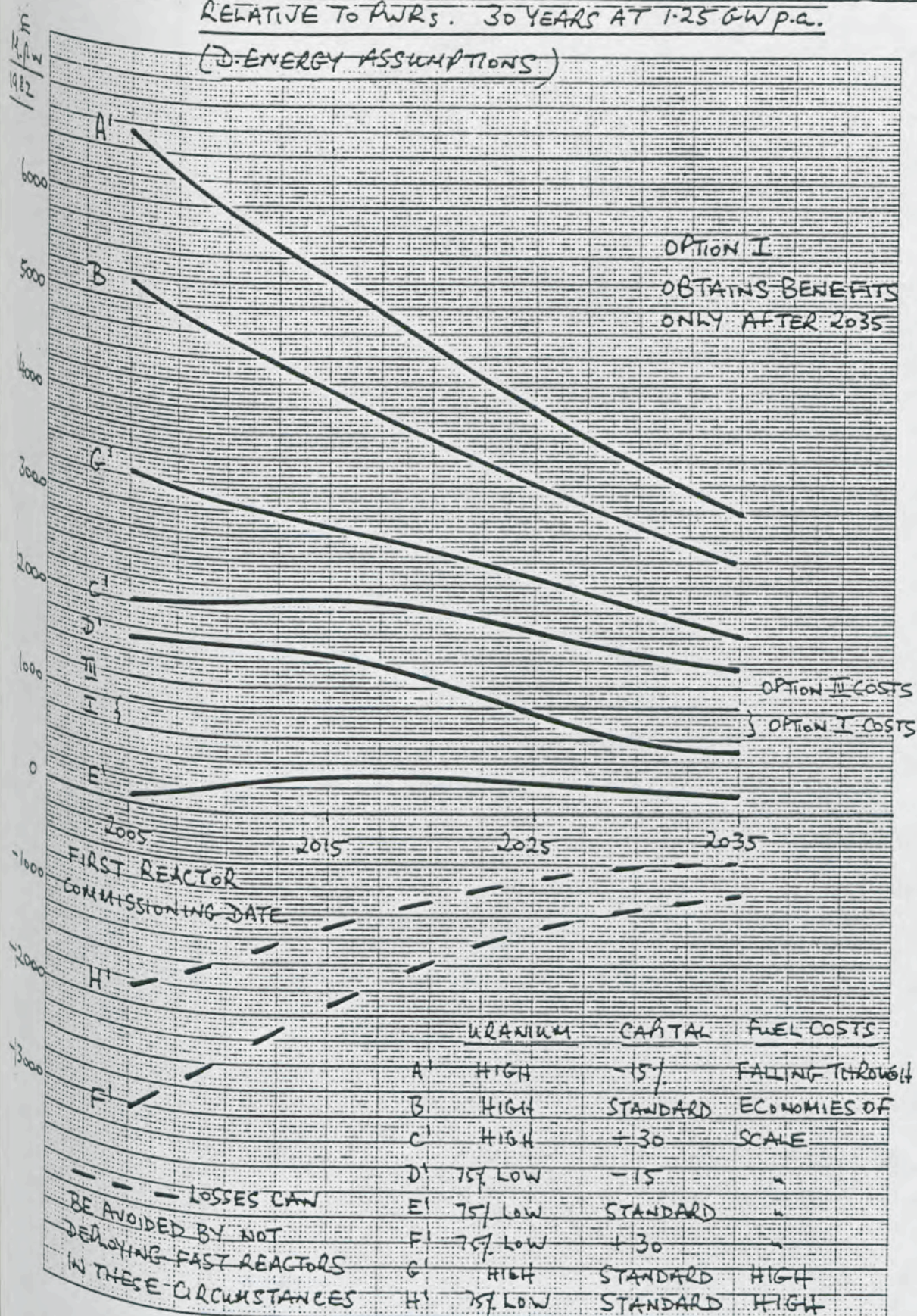
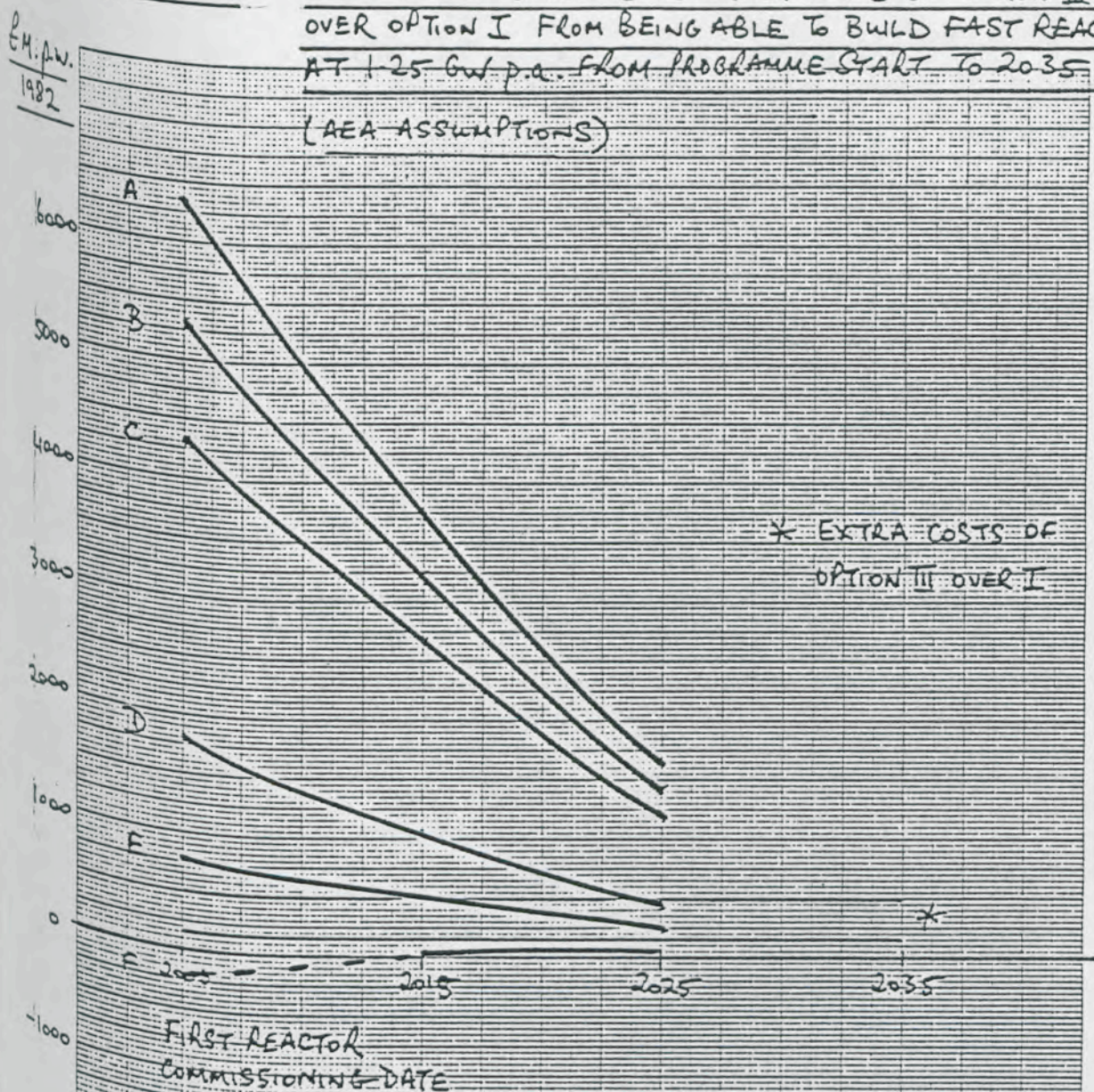


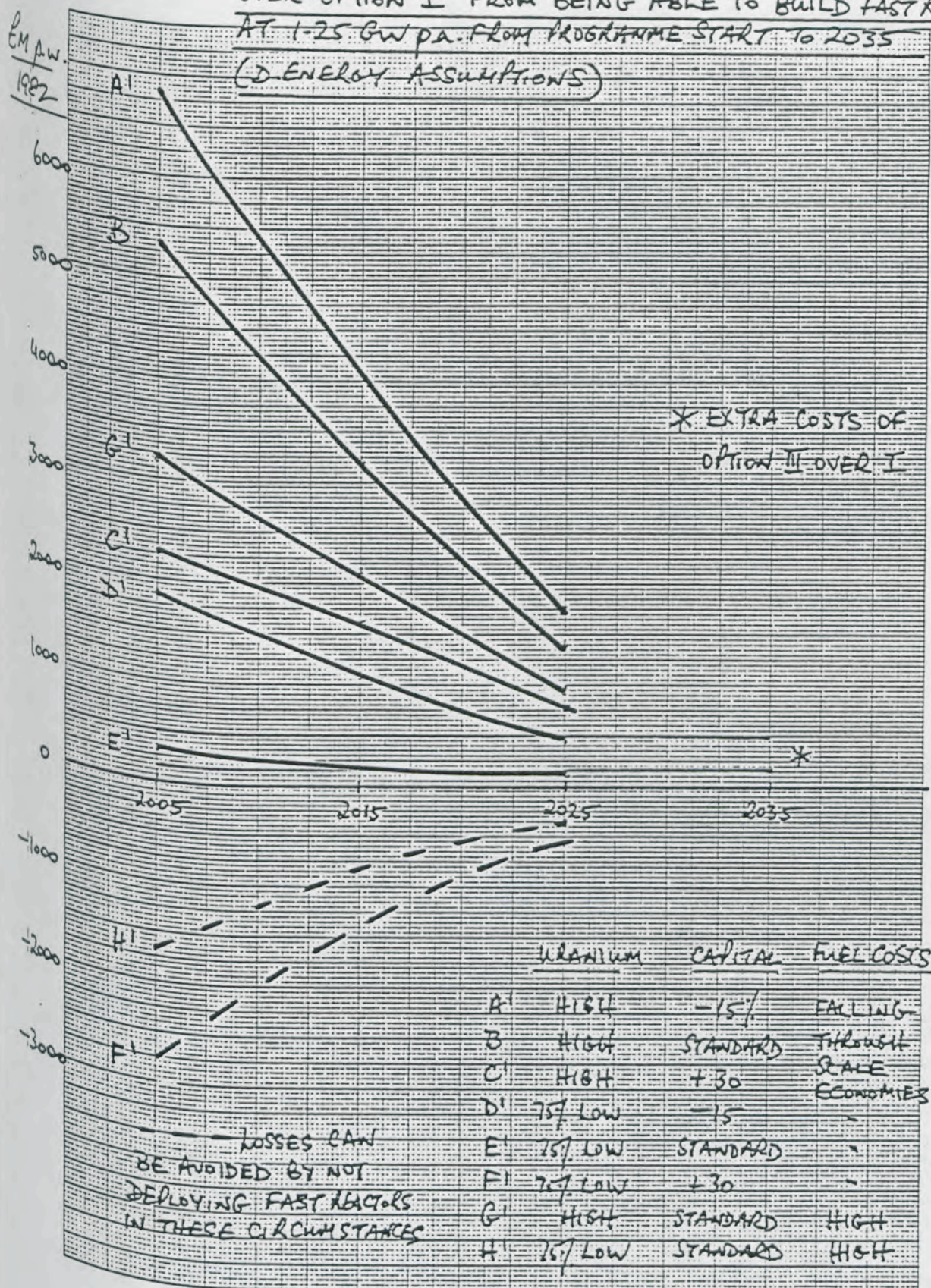
FIGURE 7 ADDITIONAL BENEFITS VS EXTRA COSTS OF OPTION III OVER OPTION I FROM BEING ABLE TO BUILD FAST REACTORS AT 125 GW p.a. FROM PROGRAMME START TO 2035 (AEA ASSUMPTIONS)



	URANIUM	CAPITAL	FUEL COSTS
A	HIGH	-10%	FALLING THROUGH
B	HIGH	STANDARD	ECONOMIES OF
C	HIGH	+10	SCALE
D	LOW	-10	-
E	LOW	STANDARD	-
F	LOW	+10	-

FIGURE 8

ADDITIONAL BENEFITS VS EXTRA COSTS OF OPTION II
OVER OPTION I FROM BEING ABLE TO BUILD FAST REACTOR
AT 1-25 GW PA. FROM PROGRAMME START TO 2035
(D ENERGY ASSUMPTIONS)



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TABLE 1.

ILLUSTRATIVE BENEFITS FROM 1.25 GW p.a. PROGRAMME*

ALTERNATIVE STATIONS	LOAD FACTOR	URANIUM OR COAL PRICES	FR FUEL COSTS	FR CAPITAL COSTS	FR BENEFIT (£M p.w. 1982)			
					2005 ⁽¹⁾	2015	2025	2035
PWR (35y)	70%	LOW	AEA	+10%	-430	-110	30	70
				STANDARD	590	590	500	390
				-10%	1610	1290	970	710
	70%	HIGH	AEA	+10%	4110	3510	2810	2150
				STANDARD	5140	4210	3280	2470
				-10%	6160	4900	3750	2790
AGR (25y)	70%	LOW	AEA	+10%	4250	2930	2020	1390
				STANDARD	5140	3530	2430	1670
				-10%	6020	4130	2830	1940
	70%	HIGH	AEA	+10%	7660	5640	4160	3070
				STANDARD	8540	6230	4570	3340
				-10%	9420	6830	4980	3620
COAL (35y)	70%	+1% P.A.	AEA	+10%	9110	6380	4430	3050
				STANDARD	10140	7080	4900	3370
				-10%	11160	7770	5370	3690
	70%	+2% P.A.	AEA	+10%	20310	16010	12470	9550
				STANDARD	21330	16710	12940	9870
				-10%	22350	17400	13410	10190
PWR (35y)	60%	LOW	AEA	+10%	-770	-360	-150	-60
				STANDARD	260	340	320	260
				-10%	1280	1030	790	580

* Programme of 1.25 GW(e) p.a. for 30 years from given date. Benefits summed over station lives against given alternative.

(1) In practice benefits would be obtained beyond thirty years.

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TABLE 2.

ILLUSTRATIVE BENEFITS FROM 1. 25 GW p.a. PROGRAMME (COST VARIATIONS) *

ALTERNATIVE STATIONS	LOAD FACTOR	URANIUM OR COAL PRICES	FR FUEL COSTS	FR CAPITAL COSTS	FR BENEFIT (£m p.w. 1982)			
					2005 ⁽¹⁾	2015	2025	2035
PWR (35y)	70%	75% LOW	AEA	+30%	-2930	-1830	-1170	-770
				STANDARD	150	250	240	200
				-15%	1680	1300	950	670
			DEn	STANDARD	-1740	-1110	-720	-480
	70%	HIGH	AEA	+30%	2060	2120	1860	1510
				STANDARD	5140	4210	3280	2470
				-15%	6670	5250	3990	2950
			DEn	STANDARD	3250	2840	2320	1800
AGR (25y)	70%	75% LOW	AEA	+30%	2080	1420	970	660
				STANDARD	4730	3220	2190	1490
				-15%	6040	4120	2800	1900
			DEn	STANDARD	3110	2050	1360	910
	70%	HIGH	AEA	+30%	5890	4440	3350	2520
				STANDARD	8540	6230	4570	3340
				-15%	9860	7130	5180	3760
			DEn	STANDARD	6920	5060	3740	2770
COAL (35y)	70%	+1% P.A.	AEA	+30%	7060	4990	3480	2410
				STANDARD	10140	7080	4900	3370
				-15%	11670	8120	5610	3850
			DEn	STANDARD	8260	5710	3940	2700
	70%	+2% P.A.	AEA	+30%	18250	14620	11520	8910
				STANDARD	21330	16710	12940	9870
				-15%	22860	17750	13650	10350
			DEn	STANDARD	19450	15340	11970	9200

* The variations span the alternative ranges requested by D.En.
Their likelihood is discussed in Appendix 3.2

(1) In practice benefits would be obtained beyond thirty years.

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Table 3

Cost and Timing Sensitivity of Fast Reactor Breakeven Commissioning Date

<u>PWR</u>	<u>Low Uranium</u>	<u>High Uranium</u>
Capital $\pm$ 20%	$\pm$ 0.25p/kWh	$\pm$ 0.25p/kWh
Uranium $\pm$ 20%	$\pm$ 0.10	$\pm$ 0.17
Separative Work $\pm$ 20%	$\pm$ 0.03	$\pm$ 0.04
Fabrication $\pm$ 20%	$\pm$ 0.02	$\pm$ 0.02
On delayed reprocessing $\pm$ 20%	$\pm$ 0.05	$\pm$ 0.05
Early reprocessing	$\pm$ 0.20	$\pm$ 0.20

<u>CFR</u>	
Capital $\pm$ 20%	$\pm$ 0.31p/kWh
Fabrication $\pm$ 20%	$\pm$ 0.04
Reprocessing $\pm$ 20%	$\pm$ 0.08

Breakeven Commissioning Date

<u>Change in CFR-PWR Generating Cost Difference</u>	<u>Low Uranium</u>	<u>High Uranium</u>
* { - 0.6p/kWh	1990	<1987
- 0.4	2003	<1987
- 0.2	2012	1987
0	2019	1999
** { + 0.2	2024	2007
+ 0.4	2028	2013
+ 0.6	2032	2018
+ 0.8	2035	2022

* PWR costs rise OR CFR costs fall by:

** PWR costs fall OR CFR costs rise by:

Notes: (i) Ordering dates will be 8 years earlier.
(ii) All figures and dates shown are approximate.

URANIUM SUPPLY, DEMAND AND PRICES.SUMMARY.

There is enough economically recoverable uranium in the ground to ensure that no serious supply problems develop for at least 20 years and possibly for much longer. However, the actual quantities of uranium that will be extracted and made available on world markets, and the prices of such uranium, depend on decisions on exploration and exploitation that are governed by current and future perceptions of demand, and on the willingness of the producer countries to allow exploration and exploitation to proceed. Major resources are concentrated in relatively few countries, none of which can be considered a risk-free source of supply because of political, environmental, and proliferation issues. The UK, with no indigenous resources, is in a particularly sensitive position, as are several other European countries and Japan.

Because of the uncertainties, few long term (~50 year) price predictions are available. Historical experience offers little guidance since the uranium market has been extremely volatile; a situation aided by the low contribution uranium price makes to generating costs at present price levels. Experience in other fields is not relevant because in general other minerals do not have as specific a role as uranium, and there is no ready substitute to act as a constraint on prices. Even a six-fold rise in uranium prices by the turn of the century would still leave new thermal reactors cheaper than new coal stations for base load electricity generation. In few cases is the mining and milling of minerals subject to such stringent and costly environmental regulations and public pressures, and these factors, amongst others are expected to force prices up in the long term.

The only published estimates of future world uranium prices are those given by CEGB in the Sizewell Statement of Case. They range from about a three-fold increase in world prices over the next 50 years on their low growth scenario to a seven-fold increase on their high growth scenario, with a larger rise in UK prices due to falling sterling/\$ exchange rates as UK loses its North Sea oil advantages. The AEA's own scenarios for uranium prices are similar but somewhat lower than CEGB's. Two independent studies support these views up to the year 2000 but make no predictions beyond that date. The world price estimates for 2030 range from \$75 to \$230/lbU₃O₈ (in 1982 prices).

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URANIUM SUPPLY, DEMAND AND PRICES

RESOURCES

1. Uranium is widely distributed throughout the world: more than one million million tonnes are dispersed through the top kilometer of the crust and the oceans. However, most of this is at very low concentrations and is not economically recoverable. There are 2.3 million tonnes of well authenticated material (Reasonably Assured Resources - RAR) with a further 2.7 million tonnes probable but less well authenticated (Estimated Additional Resources - EAR); both recoverable at costs below \$130/kgU (\$50/lb U_3O_8).
2. In addition to the quantities in these principal resource categories there are possibly further large quantities at the same cost (speculative resources) and certainly further large quantities at higher cost, as shown in Fig 1.
3. What matters is not what is in the ground but what can be made available to the consumer at a given price by a given date. The Nuclear Energy Agency and IAEA caution that their estimates of speculative resources should not be used for planning purposes and that a major part may not be found and brought into production before 2025.

SUPPLY AND DEMAND

4. The quantities of uranium that will be produced and made available to the market depend on future decisions on exploration, exploitation and stockpiling, and these in turn depend on current and perceived future levels of demand. The most recent published estimates of forward demand are those made by the Nuclear Energy Agency (May 1982) whose uranium requirements, based on once-through PWRs, are shown in Fig 2. Current international opinion (NEA High Level Workshop, February 1982) expects demand to lie close to the low bound, at least up to the year 2000, due to continued pessimism about world economic growth prospects. Planned capacity of uranium production facilities and the NEA/IAEA estimates of maximum achievable production from the five million tonnes in the principal resource categories are also shown in Fig 2. These maximum supply estimates are based on a mine by mine analysis and assume optimum economic conditions and no political or environmental barriers to mine development.
5. Despite the caution expressed in paragraph 3, it would be unrealistic to assume that none of the speculative resources will be discovered and brought into production by 2025 and to ignore the poorly documented higher cost sources (over \$130/kgU) which could be developed if higher prices prevailed.
6. In practice the maximum supply rates will not be achieved since production will be matched more closely to demand through the operation of the market. In its present depressed state existing mines have already been closed down in the US and Canada, and other mines are being worked only for high grade ore. This not only affects current output but also reduces the level of resources available in the future.
7. Whilst there would appear in principle to be no serious supply problems for at least 20 years and possibly for much longer, there are, in practice, major uncertainties. Only the RAR category can be considered firm, given that further exploration is required to confirm the EAR. The current market

is not such as to encourage exploration and the costs both of exploration and of exploitation are increasing in real terms. Major resources are concentrated in relatively few countries, none of which can be considered a risk-free source of supply. In the USA uranium trade policies have been subject to sudden change due to changing perspectives of proliferation issues and environmentalist pressures persist. In Canada mine development plans have been subject to searching scrutiny. Trade Union pressures or government changes could slow or stop sales from Australia. Conflict in Southern Africa could quickly affect supplies from Namibia and South Africa. Environmental considerations have already blocked exploitation of 300,000 tonnes of uraniferous shales in Sweden. It is therefore not sensible to plan on the assumption that the theoretical production levels from speculative sources will be achieved, Fig 2, or that additional production from the US at INFCE, Fig 3, for reasons already set out in the INFCE Group I reports.

8. With no significant indigenous resources the UK is in a particularly sensitive situation, as are several other European countries and Japan. With only two major current suppliers, Canada and Namibia, there is a clear risk of disruption. To guard against this risk in the short term, the Electricity Boards maintain a stockpile equivalent to some two years' demand; they could thus withstand a 50% shortfall in supply for four years or so. In the medium term the risk of disruption is being reduced by diversifying sources of supply: by the early 1990s uranium is expected to come from about ten sources in four or five countries. In addition, there are the options of reducing enrichment tails, increasing reactor fuel efficiency, and recycling uranium and plutonium in thermal reactors.

9. None of these measures can eliminate the risk of disruption of supplies in the short and medium term. In the longer term, even with orderly market development, shortfalls are increasingly likely to occur, particularly if the developed countries can fight their way out of the current phase of depressed economic growth or if a determined move towards greater electrification and a high nuclear contribution is favoured for policy, environmental or other reasons. In the face of the economic and resource uncertainties long-term security of nuclear electricity can only be ensured by the introduction of fast breeder reactors.

COSTS AND PRICES.

10. It is quite wrong to look at uranium as just another mineral. It has no real use other than as fuel for nuclear reactors and they have no alternative fuel. (Thorium could be used to 'breed' fuel but only after protracted delays and considerable development which no one is undertaking. Its use is dependent on the availability of U-fuelled reactors anyway). Other minerals have ready substitutes which reduce market pressures in time of scarcity (aluminium for copper, plastics for steel, etc). Only coal could act as a long term constraint on prices, but the nuclear advantage for base load electricity generation appears likely to be so large; even in the 1990s, that six-fold or larger rises in uranium price could be accommodated for new stations before coal becomes competitive.

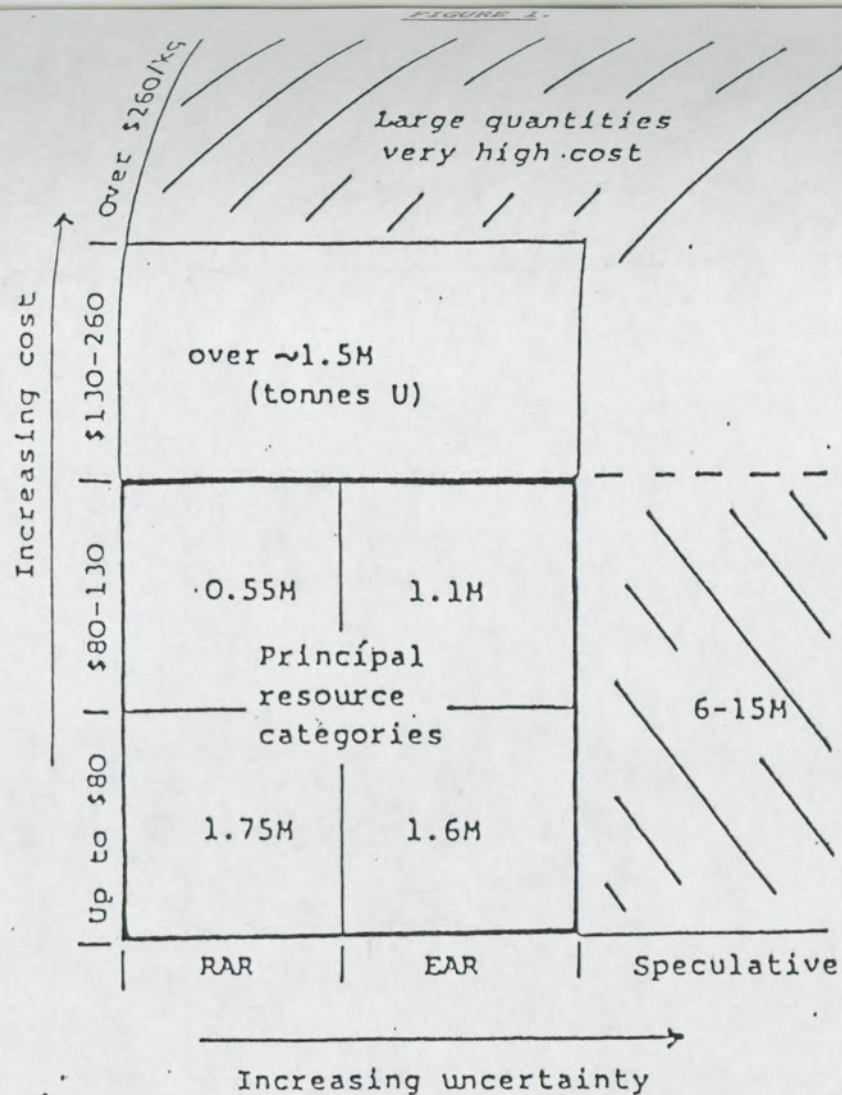
11. Base metal mining costs in general have been rising during the 1970s due to rising real wages and energy costs (Table 1) and uranium itself has been becoming increasingly difficult and costly to locate. The discovery rate per foot drilled fell from 1967 to 1975 at a cumulative 1.1% p.a. The average grade of ore has also declined during the 1970s and in some countries (USA) a higher proportion of ore will come from underground mines in the future. Furthermore uranium is radioactive and its mining and milling are subject to increasingly stringent and costly environmental regulations. All of these factors contribute to the view that uranium production costs are likely to continue rising.
12. The costs used by NEA in categorising uranium resources are the further recovery costs; that is the additional cash costs of recovering the uranium. They ignore costs already incurred (e.g. exploration) and the return needed to provide for profits and investment needed to maintain viability (e.g. continuing exploration). The ratio of selling price to cost depends on such factors as the lifetime of the mine, the required rate of return, the tax position of the operator, and the state of the market. Typical ratios of required selling price to cost based on required rate of return and mine life are given in Table 2. Since mine lives of 20 years or more are normally sought, a ratio of price to cost in the region of two would be desired by producers though in the current buyers market it could not be obtained for higher cost deposits.
13. The marginal costs of production for many mines are higher than present spot prices of \$55/kg U (\$20/lb U_3O_8) and a number of US and Canadian mines have already been closed. Present market conditions also lead to preferential extraction of high grade ore, as mentioned in para. 6, and this together with the high cost of reopening abandoned mines will lead eventually to some reduction in the quantity of uranium that can be economically recovered.
14. Given stable growth conditions some judgements can be formed on possible future prices. These will be determined by mining costs including exploration, and supply and demand factors. The AEA has developed the scenarios for uranium prices shown in Figure 5. These are designed to capture a wide range of possible development, and are based on consideration of the factors described above and their possible impacts. The figures correspond to a sterling price of £45/lb in 2030 for the low profile, and a ten-fold increase to £120/lb for the high profile in Jan. 1982 money.
15. CEGB views, based on detailed studies by the British Uranium Procurement Organization, have been published in their Sizewell Statement of Case (Table 3). Their central scenario C anticipates a 3½-fold increase in world prices over the next 50 years or 6-fold when CEGB's estimates of sterling/dollar exchange rates are taken into account. CEGB figures are shown against the AEA scenarios in Figure 5. Up to 2015 the divergence is small, although beyond this AEA scenarios are in general lower. There are no other published views on prices over this lengthy time period.

16. A confidential U.S. consultant's report prepared in late 1980 gave the figures presented in Table 4 based on nuclear capacity projections which span current expectations for 1990 and 2000. Their approach appears similar to that adopted by CEEB and the discontinuity in the 1990s stems from an expected switch from a buyers to a sellers market. A further consultant's report expected to appear shortly, anticipates new contract prices rising to \$53/lb by 1990. These sources provide some indication of the reasonableness of the CEEB projections in the near term, though they have little relevance to fast reactors which can not be widely deployed before the turn of the century.
17. In the longer term the supply of uranium and hence its price will depend on exploration and new mine development. The lead times from exploration to production are long (10 - 25 years) and have to be based on judgements about demand and profitability arising from nuclear reactors with a much shorter construction lead time (8-12 years). Present over-supply has led to mine closures and a cut back in exploration which eventually will, if it persists, lead to supply constraints. New deposits are likely, in general, to be deeper and harder to locate since the ease of location of near surface deposits has already been exploited for many decades.
18. In addition to developing price scenarios based on likely world uranium developments and market trends, the AEA has developed a mathematical model which simulates these market forces and commercial responses. The uranium resource base is modelled to allow for higher cost resources and the increased accompanying exploration. Development and exploration lead times, and costs are set by past industrial performance. The model then produces a price profile over time for a specified demand growth. The results of typical runs are shown in Figures 6 and 7 for the demand profiles given in Figure 8 which corresponds to roughly 500 GW(e) installed capacity in the year 2000, (in line with current NEA thinking) and a higher and lower capacity in 2020 of around 1500 and 1000GW(e) respectively. All reactors are taken to be PWRs.
19. Using the not un-reasonable assumptions listed at Appendix 1, the model suggests that a stable market evolution could lead to prices in the region of \$100 to \$150 per lb U_3O_8 by 2020, well above those proposed in the AEA and CEEB scenarios. The price rise in the mid 1990s is a consequence of the effect of present cut-backs on supply. [Figures 6 and 7 also include a curve to illustrate the effect (in the model) of a sudden and permanent withdrawal of 10% of resources in 1993]. The output prices from the model are the economic prices developing in a free market. The considerable reliance on long term contracts will change the picture. However, contract prices are both above and below spot prices and the two now tend to be linked since the market fluctuations of the 1970s (Fig. 4). Wide long-term divergence between the two would be difficult to sustain.
20. Our projections introduce a very wide range of prices into the economic calculations, and are sufficiently close to the profiles published by CEEB to make differences in generation costs derived using either trivial for reactors commissioned up to 2015.

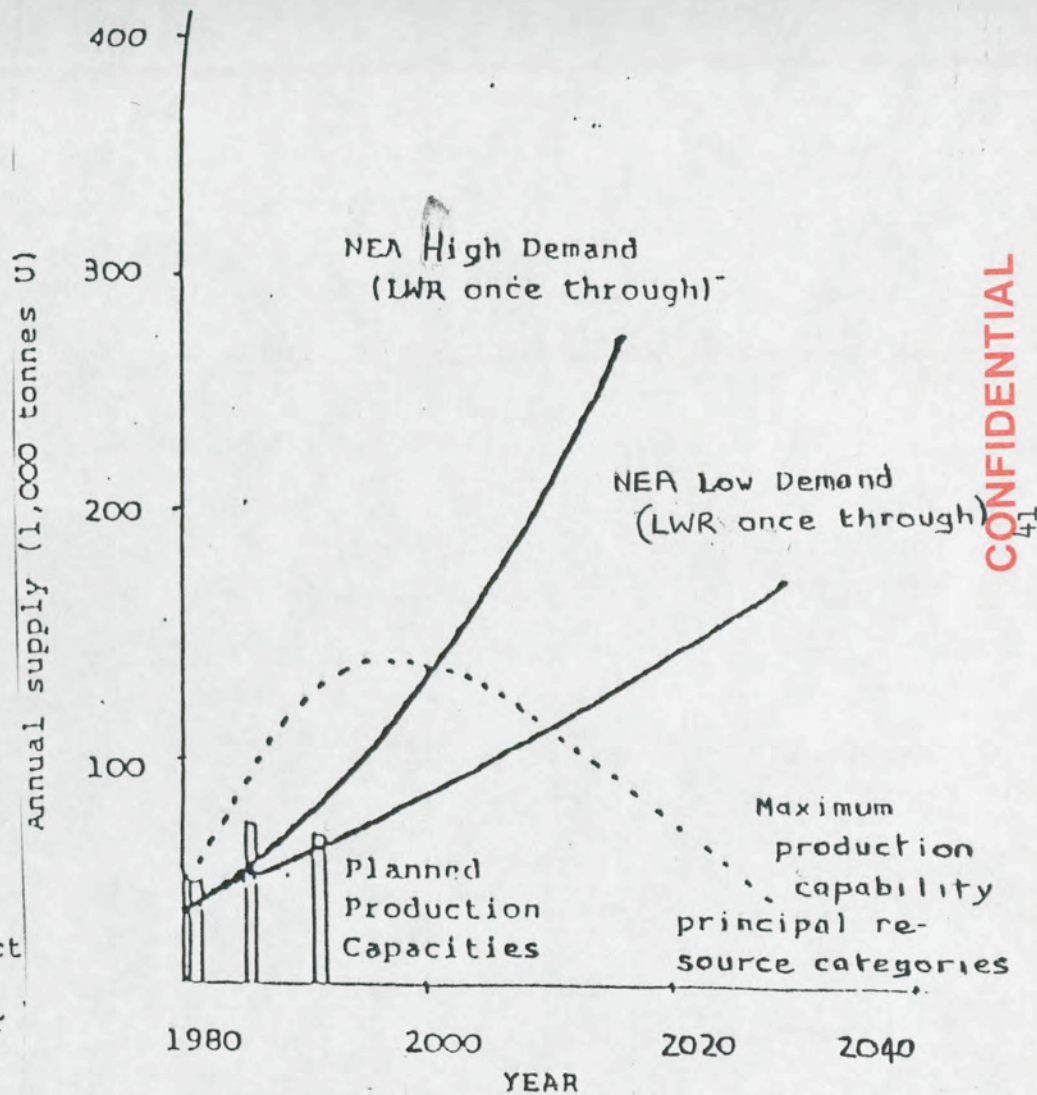
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21. Present economic pessimism has led to a marked cut-back in nuclear plans and expectations and the prices we have put forward take account of this. This may be dangerous. The great changes in growth rates between the 1890s and early 1900s, or the 1920s and 1950s or the 1960s and the 1980s, show that reliance on continuance of current experience is unrealistic. It could be that growth and energy demand will be far higher post-2000 than now seems credible, and this would have dramatic implications for the nuclear industry and uranium prices, causing the latter to rise much more rapidly due to the difficulties of expanding supply.
22. Disruptions of the sort mentioned in para. 7 and modelled in Figures 6 and 7, or cyclical effects introduced by market forces could lead to much higher prices for periods of years. The price excursion arising from reaction to the OPEC crisis persisted for many years (Figure 4), although nuclear power was contributing only 8% of the world's electricity in the mid-1970s.

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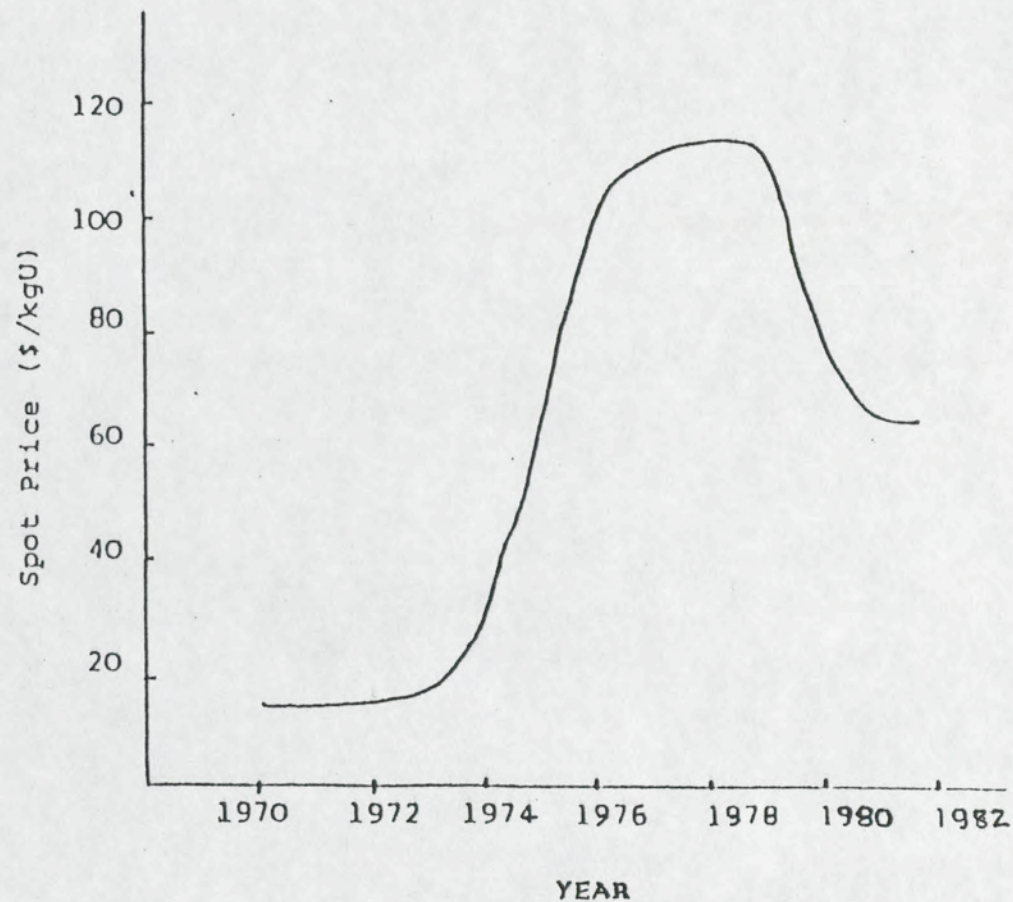
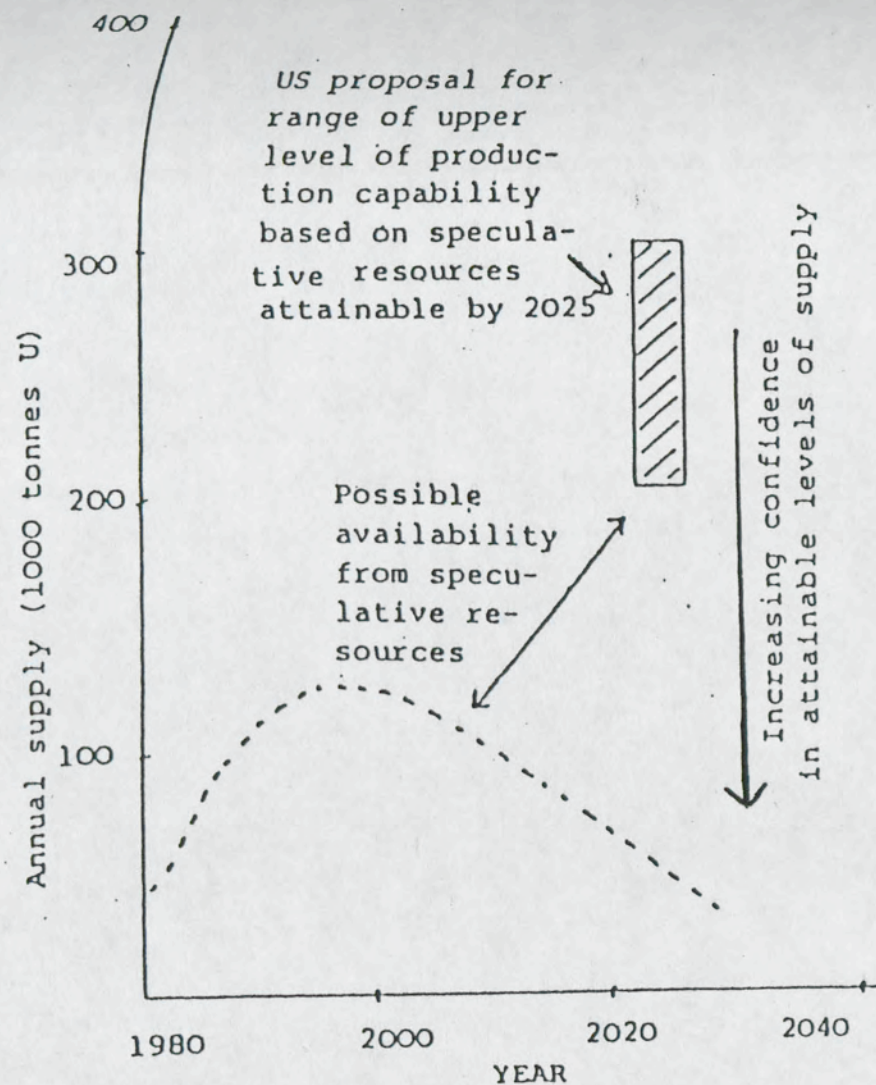


Error limits - estimates of resources are necessarily subject to error and one author (Bowie) puts the uncertainty on RAR at $\pm 20\%$ and EAR at $\pm 50\%$. US and other suppliers argue for lower errors, perhaps $\pm 10\%$ and $\pm 25\%$. Recently discovered calibration errors suggest that US estimates may be up to 20% high.

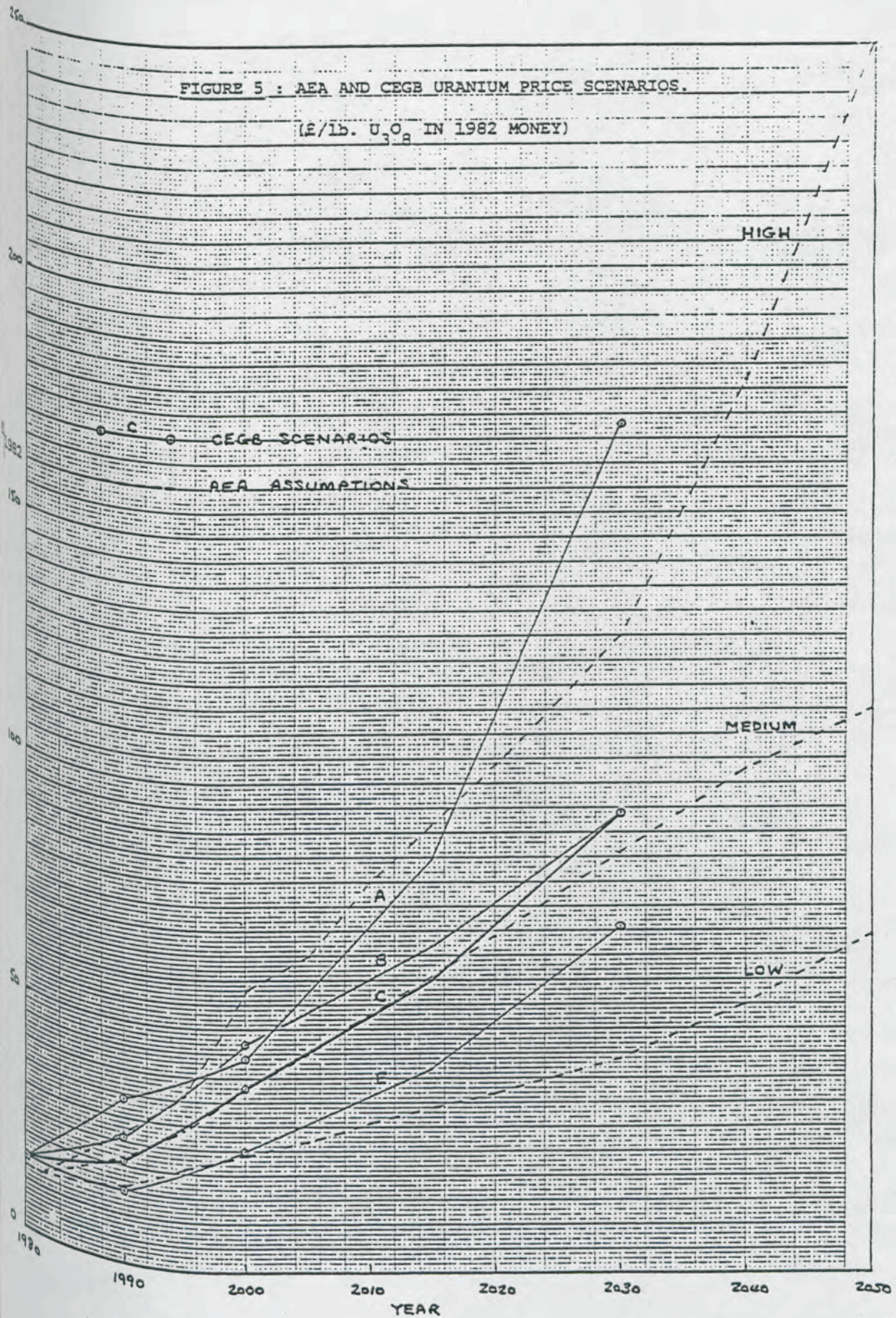


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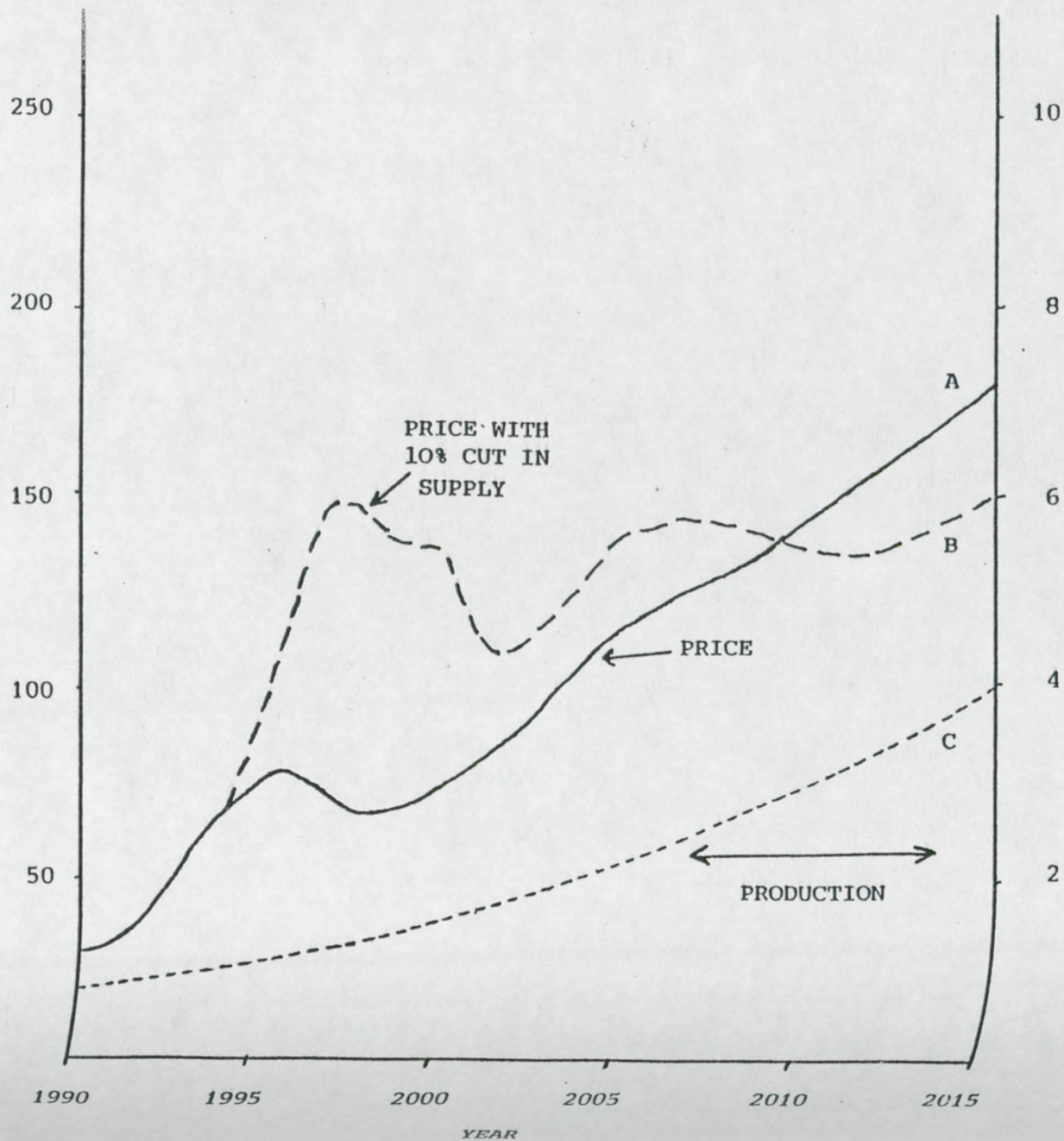
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PRICE - \$ per lb



CUMULATIVE PRODUCTION - M TES

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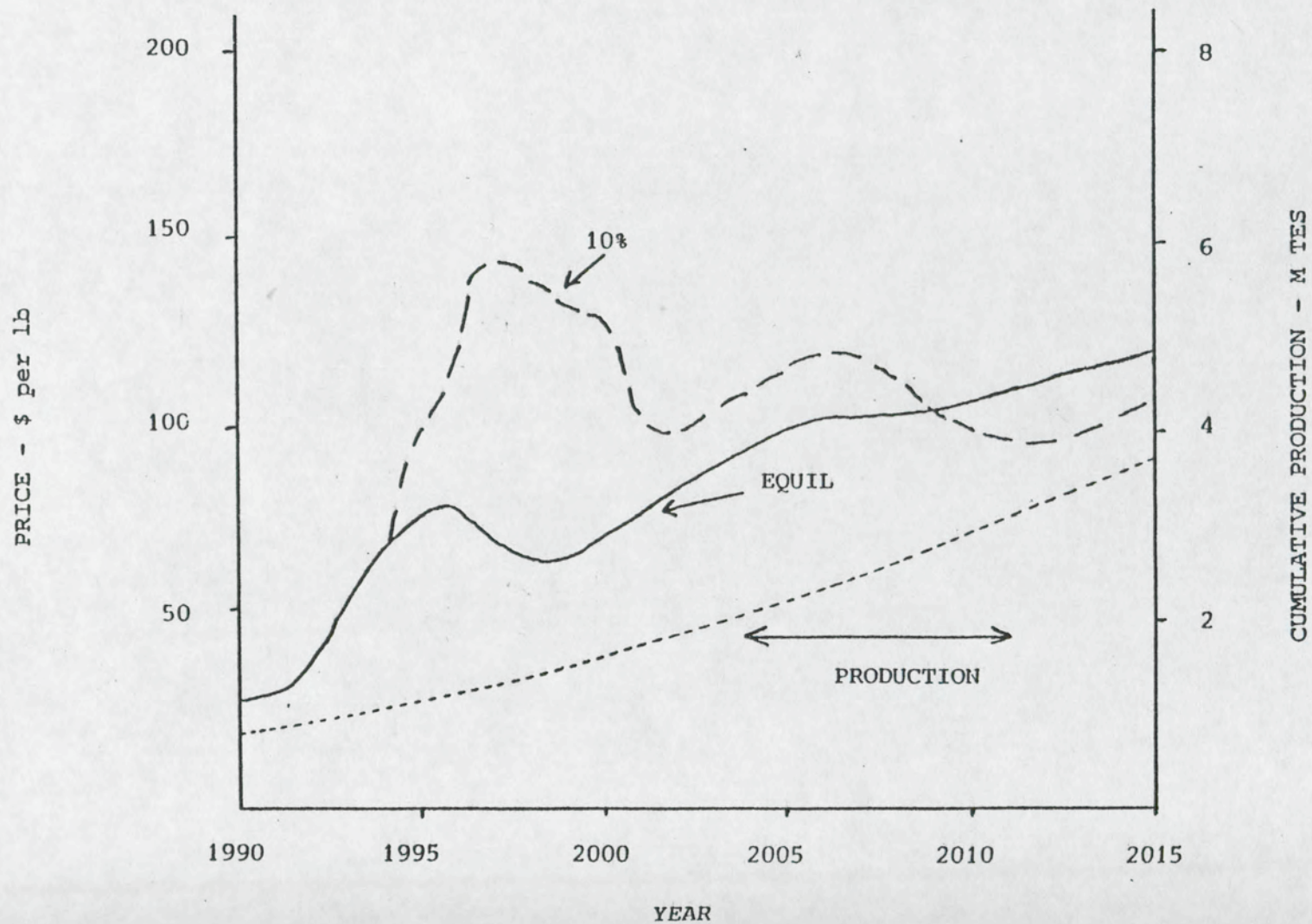


FIGURE 7 - LOWER DEMAND PROJECTION - EFFECT ON PRICE

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THOUSAND TONNES URANIUM PER YEAR

300

200

100

0

1985

1990

1995

2000

2005

2010

2015

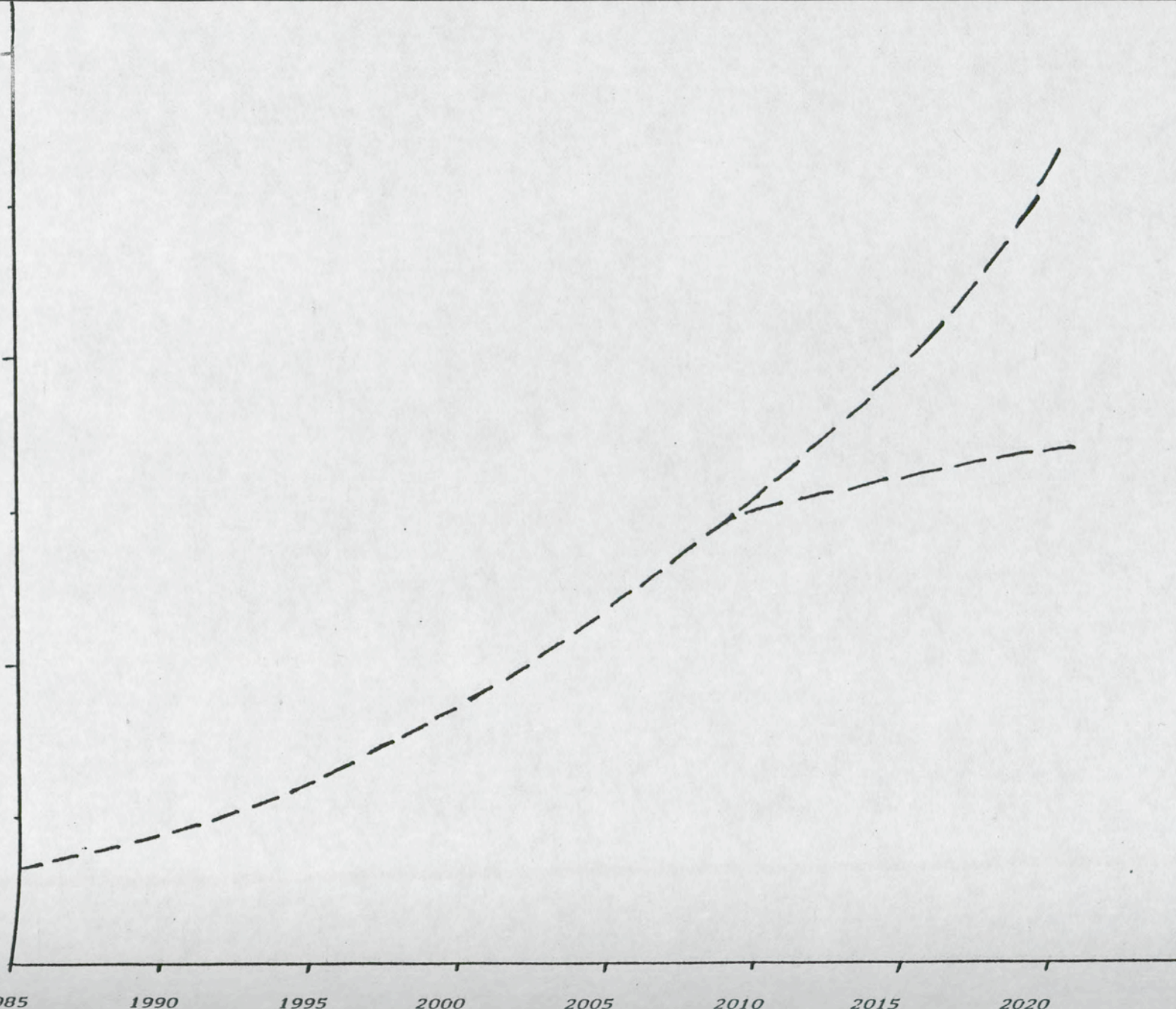
2020

YEAR

46

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TABLE 1

Annual Average Percentage Changes in Base Metal Mining
' Costs in the 1970s

	US Dollars	
	Money Terms	Real Terms
Australia : Underground	10.3	3.0
Canada : Open pit	9.2	2.0
Underground nickel	10.4	3.1
Other underground	12.0	4.6
South African : Underground (a)	17.7	9.6
Gold mines (b)	16.7	9.0
United States : Open pit	7.1	0.1
Underground	12.7	5.3

Source : Uranium Inst

TABLE 2

Mine Life	5 years	10 years	15 years	20 years
<u>Pre tax Return</u>				
15%	1.23	1.44	1.60	2.02
20%	1.32	1.65	1.87	2.45
25%	1.40	1.84	2.15	2.90

Source : Uranium Inst

TABLE 3

(a) World Uranium Prices (CEGB)
(US\$/lb U₃O₈ at March 1982 prices)

	80/1	1985	1990	1995	2000	2015	2030
High Growth	36	40	50	60	70	125	230
Medium Growth	36	30	36	43	50	80	125
Low Growth	36	25	32	38	45	65	95

TABLE 3

(b) Uranium Prices to UK (CEGB)

(£/lb U_3O_8 at March 1982 prices)

Scenario	<u>1980/1</u>	<u>1990</u>	<u>2000</u>	<u>2030</u>
A	15.4	34	44	173
B	15.4	26	47	94
C	15.4	21	38	94
E	15.4	15	25	71

TABLE 4

U.S. ESTIMATE OF U-PRICES (1980 \$/lb U_3O_8)

	1980	1985	1990	2000
Most likely	22	16	24	92
Low	22	14	18	92
Based on WCCA capacity (GWe)			1990	2000
most likely			330	531
Low			291	441

Source: Confidential consultants report by Met. Research Inc.

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APPENDIX I - BASIC INPUT DATA

Time from expenditure on exploration to availability of reserves	=	10 years
Time from decision to develop reserves to production of ore	=	5 years
Plant lifetime	=	20 years
Planning horizon of demand in establishing level of required reserves	=	12 years
Capital cost of plant (per lb of output per annum)	=	\$40
Short term price elasticity of demand	=	0.1
Short term price elasticity of supply	=	0.3

Minimum return on investment	=	0.3 x marginal cost x output
Maximum exploration funding	=	0.1 x return on investment
Minimum exploration funding	=	0.01 x marginal cost x output

Reserves function is given by:

$$\text{Reserves} = R_o \left\{ C_m \right\}^A \left\{ C_x \right\}^B$$

where

Reserves	=	thousands of tonnes (including past production)
R_o	=	2.5
C_m	=	marginal cost of production (\$/lb) and $A = 0.55$
C_x	=	cumulative spend on exploration (\$M) and $B = 0.64$ (expressed in 1975 \$ = 1.6 x 1980 \$)

The Options Considered

The seven options examined by the Atomic Energy Authority are as follows

- Option I : Closure of PFR and Dounreay, abandonment of development programme
- Option Ia : as option I but with a settled down expenditure of £10m per annum, allowing for minimal generic and safety R&D, and watching brief on international developments
- Option Ib : As option I but with retention of modest (£25mpa) R&D programme
- Option II : Continued operation of PFR until 1990's: reduced development programme
- Option IIa : as option II but with a more rapid rundown of expenditure in the short term
- Option III : proceeding towards construction of CDFR, with international collaboration
- Option IV : proceeding towards construction of CDFR on an independent basis

2. The Authority originally submitted advice on options I, II, III and IV, and at the Department's request provided subsequent advice on the variants on options I and II in order to display the implications of various intermediate scenarios.

3. As noted in the main paper one of the options we have been asked to consider is that of a core team acting as an informed buyer. Option I in basic form represents the minimum expenditure involving the long term retention of no fast reactor oriented staff. Such a course would leave the UK badly placed to make informed decisions if and when the possibility of licensing was under consideration. However, for an additional expenditure of £10m per annum (option Ia) a small core team could be established within the Atomic Energy Authority to provide a minimum of basic information and assessment of overseas technology; and additional expenditure above that level (Options Ib and II) would clearly improve the position still further, to the point in option II where, until PFR was closed down the UK would be well informed.

4. A full description of the options, and the Authority's commentary and advice on them is attached as an appendix to this paper.

5. The costs of the options to the year 2003 including expenditure already committed for 1982/83 are put by the AEA at

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Option	£m (Sept 81 prices)			
	r&d running costs	redundancy/relocation costs	CDFR	Total
I	430	203	-	633
Ia	607	152	-	759
Ib	886	115	-	1001
II	1070	68	-	1138
IIa	1195	92	-	1287
III	1200	-	520-1820	1720-3020
IV	1500	-	680-1980	2180-3480

6. The expenditures shown under options III and IV would be aimed at putting us in a position to proceed with series ordering at the end of the period, and would provide a power station which should make savings on the system. A range of CDFR costs is shown under these options to reflect the possibility that the Boards will be willing to purchase the electricity generated by the CDFR and as a result may in some scenarios be able to postpone construction of a new thermal station of equivalent output.

7. Decisions about the expenditure under options II and IIa after closure of PFR in the early nineties, can be left until later in this decade, but for the purposes of illustration we have assumed in the case of Option II that a further £300m is spent in the decade to 2003; and in the case of option IIa £500m.

8. In the PESC period the potential savings under options I and II as compared with options III or IV are

Option	£m (Sept 81 prices)		
	1983/84	1984/85*	1985/86
Option I	16	5	50
Option Ia	16	6	49
Option Ib	19	9	38
Option II	11	21	29
Option IIa	12	20	32

* The very small savings under options Ia & b in 1984/5 are because under these options the major redundancy costs occur this year.

9. The key features which distinguish these options relate to

- (i) expenditure
- (ii) timing of construction of CDFR
- (iii) impact on Dounreay
- (iv) scope for international collaboration
- (v) reliance or not on licensing

10. Expenditure: The main expenditure implications over the next 20 years are set out above. While at one extreme option I would save as much as £2.4 bn by the end of the century relative to option III, if and when any decision were taken to licence and build a CDFR, under any of options I or II, there would be additional costs in respect of the station itself, the acquisition of expertise, the transfer of technology (including price of the licences both for the reactor and fuel cycle plants), and adaption to UK requirement particularly with regard to safety. To the extent that reliance on licensing resulted in our not being able to start construction of Fast Reactors as soon as we would wish there would be further major cost penalties under options I and II.

11. Timing of construction: Only under Option III and IV would there be any commitment to the construction of a CDFR.

12. Dounreay: If option I is adopted (and less so if option II) there will be a major redundancy problem at Dounreay which in turn will undermine the prosperity of the Caithness area. Dounreay provides some 2,300 jobs or 20% of the 11,000 jobs in the Caithness area. Allowing for knock on effects the loss of some 2,800 jobs over 7 years would result from option I. While emigration might reduce the number going onto the unemployed register to about 2,000 such emigration would have an adverse effect on the housing market and the general prosperity and utilisation of the service sector. Unemployment in Caithness is currently around 10%. Measures may be possible to mitigate these effects, but there would still be a major social problem with serious political impact.

13. Scope for collaboration: Option I or variants would rule out any possibility of international collaboration. Options II and IIa might provide the basis for a limited R&D co-operation; probably as junior partner.

14. Reliance or not on licensing: Options I and II and variants would place reliance on the ability to licence. This depends on other nations proceeding with their development of fast reactor technology, and on their willingness to licence that technology to us; and the value of licensing depends also on the timescale within which such a licence might be acted on. The French are within 2 years of completion of a full scale reactor, but this design will not be suitable for commercial use. It is doubtful whether even Superphenix II which may be started around 1990 would be an acceptable basis for licensing. The US programme is still further behind. On that basis it is inconceivable that a licence for the reactor

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could be available before 2,000 and there is no assurance that a satisfactory fuel plant design would be available even as early as this; indeed any eventual licensor of the reactor might insist for non-proliferation reasons on reprocessing taking place in his own country. If a need to introduce fast reactors emerged in early part of the next century, The need to adapt foreign technology and to build a lead reactor before embarking on series ordering, to demonstrate its viability and secure public acceptability would induce a significant delay in the licensing case relative to developing our own technology. Allowing for public inquiries etc it might well not be possible to start series ordering of fast reactors under the licensing route before 2025.

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FAST REACTOR POLICY OPTIONS

1. This paper examines possible fast reactor development policies, their costs, and the extent to which benefit might be obtained from different degrees of international collaboration.

Fast Reactor Development and the Fast Reactor Option

2. Nuclear energy released in thermal reactors constitutes an economical source of power for electricity generation. However, such reactors use only about 1% of the uranium fuel fed to them, and thus the length of time for which this method of electricity generation will remain secure and economic depends on the continued availability of uranium at costs that keep thermal nuclear power competitive, and on acceptable political as well as financial terms from those countries that supply it.

3. The strategic benefit of fast reactors is twofold :

(i) they use the partially depleted uranium, together with plutonium discharged from thermal reactors and therefore increase enormously the energy which can be derived from uranium for electricity generation, by a factor of some 50-60, or by as much as 150 compared with the PWR cycle without reprocessing.

(ii) a country with a significant fast reactor generating component, and with associated plants for recycling plutonium into new fuel, becomes virtually self-sufficient in fuel for base-load electricity generation and at costs expected to be comparable in real terms to future costs from today's technologies.

Thus, in a long term optimised nuclear power programme, the uranium presently stockpiled in the UK could provide as much electricity as the country can be foreseen to need for some hundreds of years, and, for all this period, independently of political or economic developments overseas.

4. These factors - the enormous increase in a prospectively economic resource base and security of electrical power - have provided the incentive for the development of fast reactors in a number of countries (US, USSR, UK, France, Germany, Japan and others) for 30 years or so.

5. The fast reactor is not the only new energy source that is receiving research and development effort. The others have been described and listed, notably, as far as the UK is concerned, in Energy Papers No. 11 and 39. What distinguishes the fast reactor from some of the other energy sources which promise security of supply is the huge increase in effective resources which it can make available on an acceptable timescale. Successful development and in due course, a steady-ordering programme could lead to attaining fast reactor power costs which would make them comparable as investments with existing types of power station. Domestic coal production is also a large potential source of secure energy but coal has uses other than for electricity generation which will become increasingly important, and the costs of coal-fired electricity generation are likely to increase with the scale of demand.

6. The feasibility of electricity generation by fast reactors is not in doubt. Worldwide, some 13,500 GWh have been provided to national electricity systems, from development plants, enough to supply a UK city of 250,000 people with all of its electricity requirements for 10-15 years. But the timing of when electricity generation by fast reactor becomes the preferred

and most economic proposition depends upon progress with their development and demonstration as well as the rate at which coal and uranium prices rise in real terms.

7. The latter is particularly uncertain. It is not possible to forecast with any accuracy when fast reactors will be desirable as a component of the generating system in the UK or any other country. The INFCE exercise in 1979 produced a variety of such estimates ranging from the year 2000 to 2030. Other more recent exercises such as the OECD/IAEA 'Red Book' and the OECD/NEA 'Yellow Book' and subsequent discussions support the view that some countries, and in our opinion the UK, see the need for the commercial introduction of fast reactors early in the next century.

There are important features that colour judgement on when the "fast reactor option" should be available and on the timing of a development programme to lead up to it. A nuclear power station will probably operate for 30 years or more. It will take 8 years to build. A decision to build a fast reactor power station will need to consider the prospective uranium and coal prices about 15 years into the stations life, ie. 23 years ahead. Also it will take several decades to construct a programme of fast reactors which could substantially reduce dependence on imported uranium. Both these factors argue for a viable and acceptable option for the start of commercial ordering to be available early in the next century.

It may take around 15 years from a decision to proceed before we gain significant operational experience of a demonstration reactor. A decision taken within 1985 - 1990, to hold a public inquiry in respect of a demonstration project would be consistent with establishing capability in 2000 - 2005 and with a possible significant contribution to electricity suppliers in 2015 - 2020; alternatively this would be consistent with investments on the basis of a "break-even" uranium price being reached in 2020 - 2025 (see para 17).

The Fast Reactor Option in the UK

8. Two additional factors need to be assessed in considering the introduction of commercial fast reactor technology in the UK :

- (i) What is required in achieving the objective
- (ii) How far the UK programme has already progressed towards the goal.

9. To build and operate a commercial series of fast reactors requires the prior commercial demonstration of a large scale fast reactor, the appropriate skills and experience to be established in the design and manufacturing industry who will be responsible for supply; the CEB and SSEB who will be customers; NII who will formally license the stations; BNFL responsible for fuel fabrication and reprocessing. All of these organisations backed up by the experienced reactor and fuel cycle development teams in the AEA will be involved in the progressive establishment of the industrial scheme required to provide and operate safe, economic power stations and associated fuel plants which will be accepted by the general public.

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10. The two requirements of proving the prospective economics of the fast reactor to the point where the option is available on commercially acceptable terms and of securing public acceptability of the whole system have led the Authority, together with the Generating Boards and the manufacturing industries concerned, to recommend (see AEA chairman's letter to Secretary of State - 21 December 1979) that a full scale demonstration reactor (CDFR) and associated fuel plants be built in advance of the date at which series ordering of fast reactors might be needed. This judgement is one that other countries have also, independently, reached. Thus Super-Phenix is under construction in France, and demonstration reactors also feature in the plans of the USA, Germany, Japan and USSR.

11. Public acceptability depends on public perception of :

- (i) the safety issue;
- (ii) the ability of the system to satisfy the need in economic terms;
- (iii) whether the plutonium-rich fuel can be securely made, used, processed and, if necessary, transported without unacceptable constraints on civil liberties;
- (iv) whether the operation of fast reactors, and of their attendant fuel plants, can be compatible with measures to avoid increasing the risk of proliferation of nuclear weapons.

12. On current information, none of these need be a difficulty. But the issues raised (eg. by the report of the Royal Commission on Environmental Pollution in 1976) make a demonstration valuable not only through the assurance that successful operation will bring but also through the procedures of a public inquiry into a project ahead of the first series reactor (consider also the analogue provided by Sizewell 'B').

13. At present, the UK has substantial assets that mean it is a considerable way towards having secured the fast reactor option. Notably these are : -

- (i) a reactor (PFR) and associated fuel plants operating at prototype scale;
- (ii) an improved design of CDFR, of good economic promise but of which some key features need to be validated by R & D work;
- (iii) teams of designers, engineers and craftsmen in industry that are skilled in fast reactor technology;
- (iv) teams of scientists expert in the technology and in safety matters. In many of the areas concerned eg. thermal hydraulics, reprocessing these teams are among the world leaders in these subjects;
- (v) international standing in all fast reactor matters;
- (vi) a site, Dounreay, that is equipped and staffed to handle reactors, reprocessing operations, radioactive materials, and wastes covering a wider range than occurs anywhere outside one or two places in the US. Dounreay has a local population and councils that are keen to continue to work in nuclear power.
- (vii) stocks of separated plutonium

14. Most of these assets are not permanent. An important factor governing continuity is that many of the scientists and engineers are in their late 40s and 50s. A very small forward programme will not provide incentive for new staff to join to allow for their replacement in time for their skills to be passed on. Once lost, the capabilities will take a long time to re-establish and it would be very expensive.

The Aims of the Current Programme

15. The aims of the present work derive from the expectation that it is likely to be necessary to begin series ordering of commercial fast reactors in the early decades of the next century (see para. 7 above). Before commercial ordering could commence, the fast reactor option must be clearly established. Present work is directed towards minimising possible CDFR technical problems deduced from PFR experience, to ensure the option is demonstrated.

The start of CDFR and fuel plant construction in the middle-to-late 1980s would require :

- (i) a detailed design of CDFR capable of meeting safety and economic targets;
- (ii) R & D work to validate the key design features, to prove the integrity and life of the fuel and to develop the fuel cycle;
- (iii) development work in manufacturing industry on specified components;
- (iv) experimental and theoretical work on safety e.g. testing what happens under simulated fault conditions;
- (v) a project organisation to formulate a validated costed project proposal including recommendations on siting and financing.

16. Of these (i)-(iii) are aimed at improving the prospective economics of fast reactors either by reducing the capital costs of the reactor or by reducing its running costs, in particular by improved fuel performance. Half of the costs of current work are associated with running PFR and the plants linked with it, which is essential to this work. Provided there is no further reduction in the programmed resources and a satisfactory method of working with partners is found, it would be feasible to start on CDFR in 1987-88.

Generating Cost Prospects

17. There is no absolute target for fast reactor costs. It has become convenient to express the view that the aim should be to attain parity of generating costs with those of a thermal reactor at some level of uranium price. If, for example, a figure of \$150/lb was taken, then fast reactors would be economic prospects for start of operation some ten to fifteen years before the uranium price was expected to reach \$150/lb. But the pattern of uranium price behaviour in the past does not encourage confident prediction of the timing of future levels. There are limits to the amount of cheap uranium available to meet growing demand, and to the rate at which it can be produced. The price will, in the long run, rise. At some time, fast reactors will compete with thermal reactors on generating costs. Fast reactor costs are expected to fall over time as a result of R & D leading to lower construction and fuel cycle costs, of industrial experience of construction and operation, and in due course, of series ordering.

18. Precise and reliable predictions of eventual generating costs over the full operating life of a power station, whether coal-fired or nuclear, at not possible; such estimates as are possible can only be made within a range limited by factors such as predicted fuel costs over the full period, planned and predicted load factors and the estimated life of the station. On present estimates, a CDFR built during the late 1980s and early 1990s can be expected to produce electricity at a cost roughly comparable with figures within the range of costs of a coal-fired station; with the benefits of design experience and improved efficiency and of series ordering, a CFRX operating in the first few decades of the next century, could be expected to produce electricity significantly cheaper than this, and at costs within the range of likely thermal reactor generating costs. The significant enhancement of energy supply security afforded by the fast reactor could therefore be achieved at similar costs, and thus be a desirable component in the mix of generating plant.

19. [A substantial section of the Authority's paper is omitted here since the material concerned is largely covered elsewhere in the Committee paper.]

20. [The next sections analyse Options I, II, III and IV as defined in paragraph 8 of the main paper. Options I(a), I(b) and II(a) are analysed in the Appendix to this Annex. These latter Options have been examined by the Authority at the specific request of the Department, although the Authority Board do not consider that they constitute coherent programme policy options.]

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OPTION I: INDEFINITE DELAY AT MINIMUM COST

Outline

- UK withdraws from fast reactor development
- Forward development programme eliminated
- PFR closed down and spent fuel reprocessed
- Dounreay site reduced to care and maintenance basis

Benefits

Major costs of commercial fast reactor development deferred (although savings would be in the medium term rather than immediate, and perhaps negative overall if fast reactors were ultimately required).

Costs and Risks

- Serious damage to UK's ability to introduce fast reactors when necessary.
- Introduction would then take a long time.
- Prospects for thermal reprocessing possibly damaged.
- Continued responsibility for Dounreay site.
- Dire consequences for Caithness area.
- Significant staffing problems.

International Collaboration

- No prospect of commercial collaboration
- Necessity to license fast reactor technology
- Danger of technology being unavailable or politically unacceptable
- Reduced UK influence on world use of plutonium

Resource Implications

COST ESTIMATES FOR UK POLICY OF INDEFINITE DELAY AT MINIMUM COST (£M at 30.9.81)

	82/83	83/84	84/85	85/86	86/87	87/88	88/93	93/98	98/2003	Total
Dounreay	55	42	35	28	22	17	30	25	25	279
Vitrification			2	5	7	14	23			51
Other	44	27	16	3						90
Establishments	9	1								10
TOTAL	108	70	53	36	29	31	53	25	25	430

NOTE: excluding any redundancy and associated costs.

Indefinite delay at minimum costs

(a) Outline

21. UK resources would not be further committed to fast reactor development, and the forward programme would be reduced as quickly as possible commensurate with the safe and controlled closure of the large and small scale facilities. This would involve the closure of the PFR and the phased closure of its fuel cycle and ancillary plants mainly located at Dounreay: there would be no justification for continuing to operate PFR purely as an electricity producer. The size and nature of the plants, taking account of their radioactive content, would require that their closure was carefully controlled and phased over a period of years. It is likely that a period of some 7 years would be required before Dounreay could become a largely non-operational site to be retained on a care and maintenance basis, by implication requiring minimum expenditure; however, to deal with all the wastes and decommission the reactor and fuel plants, to enable operational staff to be completely withdrawn, would take very much longer and cost a considerable sum.

(b) Benefits

22. The clear medium term benefit of this course of action would be financial although there would be few savings in the early years; UK fast reactor funding would be sharply reduced, at least for the time being. However, it should be noted that the timescale for closing down large scale plants and facilities like those at Dounreay is such that little financial saving could be expected in the early years (estimates and PESC period).

(c) Costs and Risks

23. The cost of bringing Dounreay simply to a care and maintenance level and keeping it in that state could be some £280m up to the year 2003, plus the costs of coping with the other ramifications and any provision for staff redundancies or staff redeployment arising from such an option.

24. During the first year following a decision to adopt this option, preparations for PFR closure would be put in hand and a programme of final experiments - to some of which the Authority are contractually committed - would be carried out. Following shutdown, the fuel and breeder elements in PFR would be unloaded, and the liquid metal coolant system emptied and passivated for disposal; this would take some two years to complete. Through this period, the reprocessing plant would operate to clear the backlog of irradiated fuel and begin reprocessing the final core and breeder charges, after an appropriate cooling period; to complete the reprocessing of all the discharged fuel and breeder material would take a further two years. Recovered plutonium nitrate would then be shipped to Sellafield. Preparation for the treatment of the resulting highly active liquid waste would involve construction of a vitrification plant which would operate through the following four or five years, while the reprocessing plants were decontaminated and partly decommissioned to ensure that there could be no subsequent radioactive release. DFR, DMTR and a number of buildings throughout the site would also need further decommissioning to reach a minimum care and maintenance state.

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25. The financial implications of this programme of work necessary in bringing the site to a care and maintenance condition are set out in the main table above. Apart from the major programme components outlined in the previous paragraph, these expenditure levels allow for necessary support services during the rundown period. Assistance from analytical laboratories, engineering support, health physics monitoring, plus electricity and water supplies would be necessary during this period to ensure a safe transition to a condition of minimum surveillance. The nearby MOD establishment would be required to take over some services currently provided by the AEA. Costs would be critically dependent on the total work load on the Dounreay site. To maintain an operational site and necessary overheads, solely to support a decommissioning programme would be extremely expensive; if, however, the site were operating to carry out alternative programmes of work to fast reactor development, the costs of a decommissioning programme would be significantly reduced. It would not be possible on any short timescale to close the Dounreay site.

26. Thus Option I makes provision for taking the Dounreay site to Stage 2 Decommissioning, that is to a stage where it has been made safe for decades but retains the opportunity for its subsequent re-use as a nuclear site. This is considered to be the correct policy in the absence of any substantial value arising from an alternative use. Accordingly, no consideration has been given to extending decommissioning to Stage 3, that is to the "green field" stage that would permit general use of the site. UK policy does not assume that nuclear sites will be taken to this ultimate stage of decommissioning except where a special need arises and then only after a reasonable period for radioactive decay. No such action can be firmly planned or costed until Government decisions have been made on radioactive waste disposal policy covering the nature of waste packaging and the method of ultimate waste disposal. Even then, detailed engineering assessments would be required to establish broadly the cost of taking the Dounreay site to Stage 3 decommissioning. Guidance on the cost of full decommissioning of the Dounreay site is, nevertheless, possible by making assumptions on waste disposal, for example that use of sea dumping with current packaging specifications can be increased and that highly-active vitrified waste will be stored on site as an interim measure.

27. A number of points should be noted in estimating total decommissioning costs of Dounreay:

- (i) Fast reactors have favourable characteristics compared with gas-cooled reactors, the most notable of which is the substantially smaller volume of radioactive material in the core - about a factor of ten lower than from a corresponding Magnox station and of three lower than from an AGR station.
- (ii) The Dounreay site contains a wide range of other radioactive plants in addition to PFR, notably two other reactors (both shutdown), fuel reprocessing plants and post-irradiation examination facilities and laboratories.
- (iii) The Dounreay site also contains authorised radioactive waste disposal facilities. These would not be removed - but fenced off so that they would not impede general use of the rest of the site.

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8. The additional cost of fully decommissioning the Dounreay site is estimated at about £60m for the three reactors, £30m for the fuel plants and examination facilities, and £40m for waste treatment, disposal, storage, etc. For policy purposes an expenditure of £150m could be assumed, this estimate including demolition of site buildings but excluding any waste repository charges. This task could be expected to extend over about 20 years and allow advantage to be taken of radioactive decay and provide flexibility for manpower requirements.

9. Apart from the impact on Dounreay, a decision to close PFR and its associated fuel cycle and waste treatment plants would also have a major impact on the rest of the Authority; reductions would be required at Winfrith and Harwell, and there would be a possibility that other laboratories in the North of England would have to be closed. This again would take a number of years. Research effort might be redirected towards keeping abreast of developments for the more efficient use of uranium in existing or other fuel cycles. The decision would also have severe repercussions on general industry, affecting NNC, BNFL and the Authority's other suppliers - large and small. Alternative sources, probably overseas, would have to be found for fuel for our materials testing reactors. Finally the severe economic and sociological impact on Caithness must be considered. The Authority is the major employer there and the effect on the whole community would be very serious.

10. Because of the complex and mutually dependent nature of the Authority's programmes, many more staff would be affected by a decision to withdraw from fast reactor development than those employed directly on fast reactor programmes. Overall, including support staff and industrial employees, some 4000-4500 Authority employees would be displaced, with inevitable redundancies. Staff at Authority sites would be affected. The effect on the Authority as an organisation would therefore be profound as would be the effect on Caithness, particularly when multiplier effects are considered. The apparent cost of the Authority's other programmes would also rise significantly in the short term as overhead expenditure was reallocated.

11. Some indication of the possible costs of redundancy, relocation and reallocation of staff costs for the option considered in this section is given in the estimates below:

83/4	84/85	85/86	86/87	87/88	88/93	93/98	98/2003
17	44	19	18	20	63	20	2

12. In practice, the Authority could hope to reabsorb some of the direct costs arising, and pass some on to commercial customers. If a decision was taken to decommission the Dounreay reactor and plant, this would reduce some of the staff costs above. However, the total of decommissioning and remaining staff charges would be roughly the same order as shown above.

2. Finally, abandonment of our own programme would damage prospects for public acceptability of the fast reactor system, weaken the UK's influence on world non-proliferation policies and put in doubt BNFL's long term future reprocessing business. The termination of work towards CDFR would add to problems in manufacturing industry and NNC at a time when other power station requirements were declining.

(c) International Collaboration

The possibilities for international collaboration in such a course of action are non-existent if by collaboration is meant worthwhile pursuit of complementary or integrated programmes. Even if the UK were proved wrong in assuming that fast reactor 'would not be needed in the foreseeable future, it would be necessary both to import technology and take licences on overseas designs in order to support commercial fast reactors. The UK could not rely on there being beneficial commercial competition to sell us a licence; having got out of the fast reactor field, potential licensors would be well aware that the UK would be obliged to pay a high price if required. Nevertheless there would be little to be gained by a commitment to a particular national technology at an early stage. It would be more sensible to save any licence fees payable until a fast reactor component became necessary, and at that time hope to choose between competing technologies.

This course of action assumes that other nations, France or Japan, for example, would continue to develop fast reactors, and would be able to make available appropriate technology in the event of the UK, after all, deciding on a commercial fast reactor programme.

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OPTION II: INDEFINITE DELAY WITH MAINTENANCE OF MINIMUM PROGRAMME

Outline

PFR to operate to early/mid 1990s

Forward programme reduced and oriented to generic and safety issues

Maintenance of informed buyer status

Benefits

Significant reduction in expenditure.

Maintenance of UK position as an informed buyer.

Maintenance of some fast reactor expertise.

Maintenance of Dounreay.

Costs and Risks

Necessity to review programme again in late 1980s

Loss of design expertise and industrial prospects.

Loss of demonstration step leading to delayed ability to adopt FR

Significant staff displacements in all organizations at a time when other workloads tending to decrease

International Collaboration

Little chance of significant collaboration on commercial development

Possible low level exchanges with USA

Necessity to license overseas technology

Resource Implications

*

	82/83	83/84	84/85	85/86	86/87	87/88	88/93	93/98	98/2003	Total
Operational (net)	36	29	25	22	19	18	61	40		250
Fabrication and Vitrification Plants (Capital)			1	3	6	10	40			60
For hire/reprocess	11	11	10	10	12	10	50	36		150
Present/Safety:										
AEA	52	42	35	30	30	30	149	139	73	580
RNC	9	1								10
SNPL		1	1	1	1	1	5	5	5	20
TOTALS	108	84	72	66	68	69	(305)	(220)	(78)	(1070)

*NOTE: Costs in later years dependent on new programme decisions to be taken before 1990 (see text). These figures exclude any redundancy and associated costs.

II Indefinite delay with maintenance of a minimum programme

(a) Outline

35. The main distinction between this option and the previous one is that PFR and the associated Dounreay plants would be maintained in operation. Development work would be slanted towards a more generic programme such that further consolidation is made on the fuel cycle, particularly in fuel fabrication and reprocessing. Also expertise will be retained in the safety and safety-related areas. The maintenance of Dounreay as an operational fast reactor site is based on the premise that retention of a fast reactor centre with its operating plants together with a relatively small R. & D. team covering generic aspects of fast reactors represents one way of sustaining a wide expertise on the system. The R. & D. component, although small, would provide technological cover across all disciplines. Past experience has shown that such a policy ensures availability of experienced technologists (reactor and fuel cycle) and that R. & D. staff benefit greatly in their understanding of the background technology from association with problems arising in operating plants. In addition, the design and development team working on the fuel cycle would soon lose competence unless their efforts were directed towards specific hardware, in this instance the improved efficiency of the PFR fuel plants.

36. Medium term policy would therefore be to maintain the UK's position as an informed buyer of overseas fast reactor designs and substantial other technology, when the need arose. This would involve the ability to assess and operate the fuel cycle, to provide sufficient technical knowledge to support the large expenditures involved, and to give advice to the safety regulatory system. This position could be attained by continued experience of PFR operation and pursuing development of the fuel cycle. It should be noted that it would take a number of years to restructure the programme in this way, and the change would have a significant impact on NNC and other parts of the industry by severely reducing the work required. There would be no outlet for surplus staff in other areas of the nuclear industry.

37. It should be noted, however, that this is an interim option only; in only a few years, further decisions would need to be taken. PFR is likely to be shut down by 1995; if the Dounreay site, and the associated UK fast reactor expertise, are to be maintained beyond that point, a further review of the programme would have to be undertaken in the late 1980s; the options being an expanded fast reactor programme, a further holding programme or withdrawal from future development as in Option I. It is unlikely that there would be good prospects for international collaboration at that stage, since the USA, France and Japan may have settled arrangements between them. Alternative uses of the Dounreay site, in the absence of a decision to pursue fast reactor development beyond PFR close down, are being considered by the Authority.

(b) Benefits

38. There would in the medium term be a possibility of reducing costs in adopting this option, although the savings would not be as great, for example, as with Option I. The policy also allows

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for the preservation of Dounreay and the UK experience in the fast reactor team, important national assets, until the mid-1990s. This would allow the UK to postpone for a few years a decision on a CDFR project, during which time the timescale for economic fast reactor introduction would become clearer, and the decision process more firmly grounded. The UK, by retaining background expertise, would retain the ability to introduce fast reactor technology more quickly when required, than would be possible in the absence of a fast reactor programme, even though overseas technology would have to be imported.

(c) Costs and Risks

39. If such a programme were to continue to the 1990s, the total cost could amount to £600M to the end of this decade. This figure excludes any direct investment which the electricity supply industry might wish to make in overseas projects to help maintain an informed customer status. It allows for the maintenance of a significant programme of work at the Dounreay site, including the operation of PFR with its full ancillary fuel plants. This would be complemented by programmes of R. & D. at other AEA establishments with the objectives mentioned above, but which would necessarily represent a marked reduction from the current programme. Costs shown for later years of this option are indicative only, and cannot represent coherent programme planning before a further review in 1988-90, but could amount to total costs of around £1100M if it is decided to operate PFR until the mid-1990s.

40. Clearly there would be a significant impact on the Authority, and a large number of staff would be displaced, both at Dounreay and at the Northern Division Laboratories; one or more of these might need to be closed down. When the effects of subsequent programme restructuring are taken into account a total of about 1,200 to 1,500 staff would be displaced over the Authority as a whole; when the total numbers of supporting staff are taken into account, the effect on the Authority can be seen to be severe. Possible AEA staff displacement costs over the next 10 years are shown below, on the programme assumption that PFR is operated until the early/mid-1990s.

	1983/84	84/85	85/86	86/87	87/88	88/93
£M	8	9	10	9	7	25

There would also be staff displacements at BNFL and NNC.

(d) International Collaboration

41. There would be almost as little chance of substantial international collaboration under this policy as under a minimum programme. Certainly there would be little point in seeking an agreement with the French. Given the relatively advanced stage the French programme has reached, and the minimal UK programme postulated, any such agreement would again amount to the UK seeking French technology. There would be no advantage in seeking what would effectively be a licence, many years before it was wanted. Funds would be committed for a number of years

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ahead and the UK would lose the power to choose the most suitable fast reactor design when the time came. Some continuing collaboration with the US, albeit with limited objectives, could be mutually beneficial, especially if the PFR reprocessing plant could be used to reprocess, under contract, fuel from US test reactors. However, such a course would necessitate buying French or American commercial technology eventually anyway.

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OPTION III: MEASURED PROGRESS TO ESTABLISHING FAST REACTOR OPTION WITH INTERNATIONAL COLLABORATION

Outline

Continuation of existing programme, with commitment to demonstration project(s) with overseas partners

Benefits

Assurance of commercial fast reactor ability
Savings on development costs
Savings on shared process plants
Advantages to UK nuclear plant and fuel cycle industries in home and overseas markets

Costs and Risks

Outcome uncertain, dependent on achieving beneficial collaboration

Requires significant resource commitments

International Collaboration

By definition necessary

Relative merits of France and US dependent on agreement that could be negotiated

Resource Implications

POTENTIAL COSTS TO UK WITH INTERNATIONAL COLLABORATION (£M at 30.9.81)

(Based on CDFR built in the UK, collaboration with USA)

	82/83	83/84	84/85	85/86	86/87	87/88	88/93	93/98	98/2003	Total	Credit ex USA	Net Total
Reactor and Fuel Plant Costs												
Capital						30	1090	150		1270	100	1170
Operations								50	100	150	-	150
Plants: Capital						3	158	149		310	60	250
Operations								112	130	250	-	250
Total						33	1248	461	238	1980	160	1820
Reactor: PWR Capital and Operations (inc. Fuel)						20	740	265	275	1300	-	1300
Net Costs												
Development Costs						1.33	508	196	-37	680	160	520
Reactor/Industry, BNFL												
and Plants	61	63	66	70	106	117	367	147	103	1100	300	800
Development Costs	47	40	36	35	37	38	151	16	-	400	-	400
NOTES: P	1058	103	102	105	143	155	518	163	103	1500	300	1200

NOTES: For costs of collaboration with France or USA/JAPAN, see text

Reactor and Fuel Plants "Capital" includes design and project costs.

"Interest During Construction" has been excluded pending definition of the financing arrangements.

III Measured progress to establishing a fast reactor option with international collaboration

(a) Outline

42. Under this option the UK would build on current skills and resources, minimizing additional demands for men and money by moving forward with an overseas partner with phased and possibly shared demonstration projects. The phasing could take account of demands for resources on other projects and would include shared process plants. The policy would be to aim at a demonstration project on a timescale chosen in consultation with overseas partners with the Generating Boards paying the cost of an equivalent thermal reactor and the Government (and overseas partners) meeting the extra costs - the overseas partner probably providing his part as equipment or design services. We should include provision for our contribution to our collaborator's demonstration reactor on a similar basis on a later timescale but would propose that our process plants should be first and cover the initial requirements for the overseas reactor. The construction date for CDFR would be flexible over a range of up to 5 years to fit in with the collaboration programme. Delay will create some increased problems, e.g., maintenance of viable teams and would increase the proportion of total costs that were Vote funded. For a UK CDFR it is assumed in this paper that there could be a public inquiry as early as 1986/7 and that construction would begin in 1988. This timetable has the additional advantage of phasing in CDFR work for NNC and CEGB as other power station work falls off.

43. It should be noted that since it is explicitly dependent on securing appropriate overseas partnership, this option is conceptually distinct from the other three. Before such partnership agreements are reached, a commitment to this course can only be provisional; UK decisions over an eventual programme would necessarily be influenced by the requirements of partners. Until collaborative agreements are concluded, this is a difficult option to cost with confidence. There is a danger that prospective collaborative partners could reach agreement among themselves, if we were seen to delay unduly during current discussions.

(b) Benefits

44. The high cost of fast reactor programmes and the benefits of early reliable operation of a large demonstration plant make international collaboration very attractive. The formation of joint design and development programmes and, in particular, the sharing of the high capital costs of reactor and fuel cycle plants could lead to substantial reductions in the total initial costs of any national "go-it-alone" programme. The expected need for each national partner to have a commercial-sized reactor plant lends itself to a phased progression of demonstration plants which would allow each country to reach the stage of being able to operate a series of power stations earlier than if it acted on its own. It will also lead to an earlier but limited demonstration of reprocessing, with 10 years interim storage of solid and liquid wastes. The degree to which reprocessing is demonstrated will depend on collaboration negotiations. In the event of the first reactor being built elsewhere, the cost of returning the vitrified

waste is deferred and not shown in the tables. A collaborative option has the added advantage that it does not waste but builds on the UK's skills and resources whilst incorporating those of overseas partners. Links and partnerships forged with overseas companies should benefit UK industry.

(c) Costs and Risks

45. The impact of a collaborative venture on the costs of a UK commercial fast reactor programme is difficult to quantify in detail prior to serious negotiation. Assumptions as to the choice of partner, and then as to the siting of the various demonstration plants significantly affect the final cost estimates.

46. The possible costs of a collaborative venture with America are outlined in the summary table above. The costs are approximately £1720M net, or £3020M gross offset by a PWR credit of £1300M. Should Japan join the project in a trilateral project, the total contribution from overseas partners to a UK CDFR, UK fuel plants and research and development could be expected to be slightly greater, but it is not possible to quantify this.

47. The phasing of expenditure on capital costs and research and development for a full programme of one demonstration reactor in each participating country is shown in indicative form in the attached diagrams. These show the cumulative expenditures are very similar whether the first demonstration reactor is built in the UK or the collaborator's country. If built abroad, UK expenditure is delayed only slightly in the medium term. In purely financial terms, the additional costs of a collaborative programme will depend on the extent to which an extended UK research and development period is offset by gains derived from the method of overseas financing adopted for a reprocessing plant built in the UK. However, there will in practice be substantial extra benefits. At the end of the programme, the UK, along with the other partners, will receive the benefit of having constructed more than one demonstration plant, together with that of significant capital expenditure deferment, and will have achieved the industrial capability of supplying fast reactor technology to an international market.

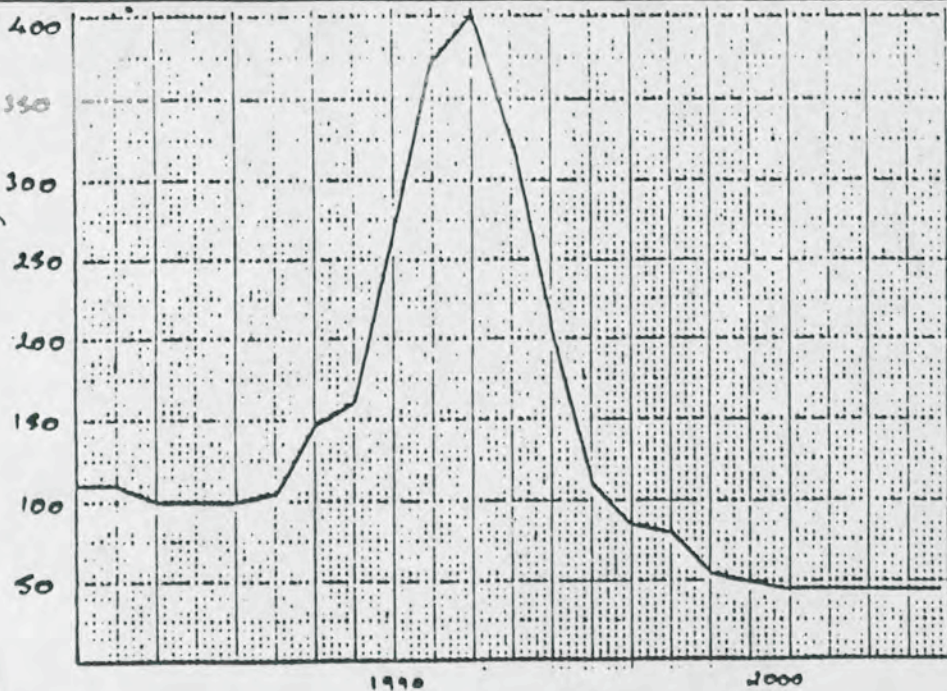
48. It is assumed that all partners would make broadly similar contributions to subsequent demonstration plants, irrespective of the siting of the first demonstration reactor - on the basis that one would be built in each of the collaborating countries. (In the coloured histogram showing the costs of the four policy options the contribution to the second reactor is excluded.)

49. The costs of a collaborative project with France should be fairly similar to those for a US/UK project; however the phasing of contributions by the UK to a French reprocessing plant (PURR), and the assumed lack of a French contribution to a UK CDFR, could mean that some UK expenditure would be required slightly earlier than under a UK/US agreement.

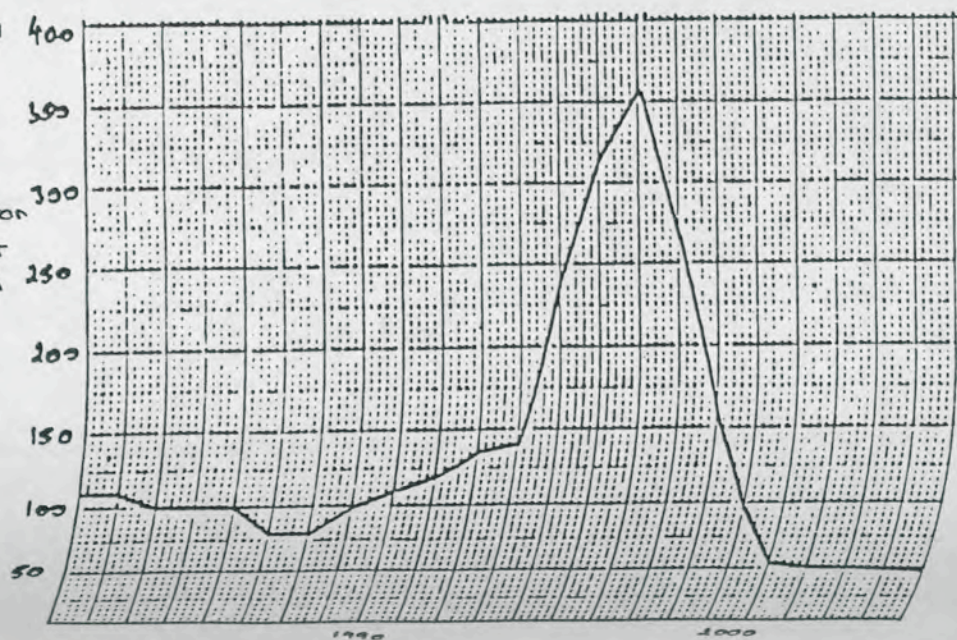
50. With this option the resources assumed in the current Estimates and PES submissions should be adequate for the three years up to

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1st
Reactor
Built in
UK

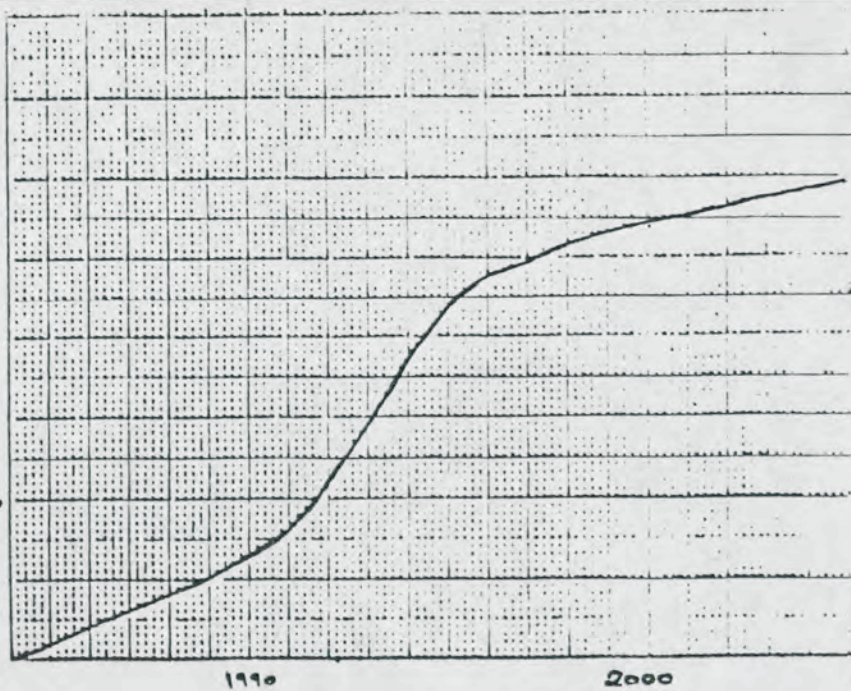


2nd
Reactor
Built
in UK



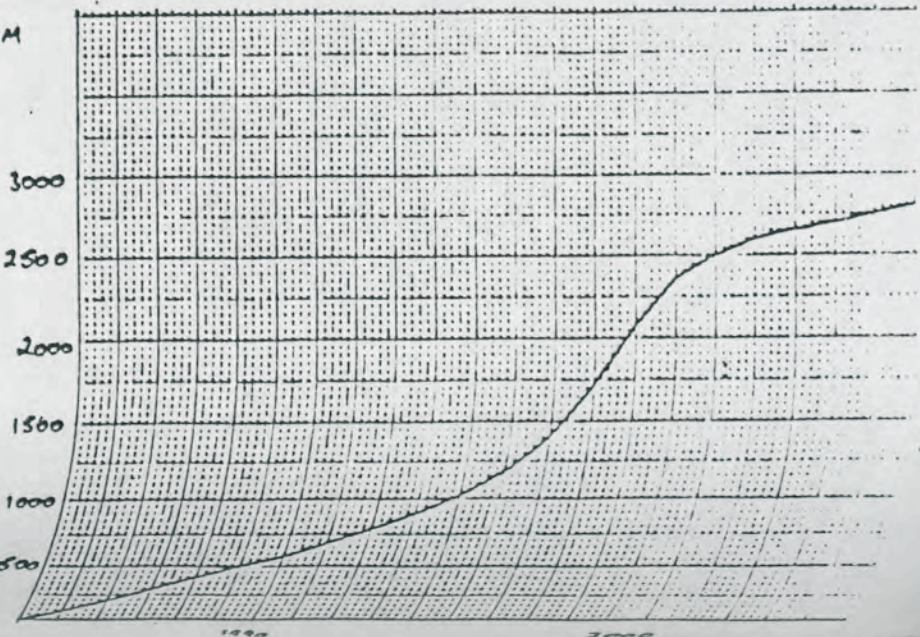
£M

3000
2500
2000
1500
1000
500



£M

3000
2500
2000
1500
1000
500



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the Public Inquiry. At that stage, however, some enhancement would be essential, especially in the engineering area, if the proposed start construction date for CDFR was to be met.

(d) International Collaboration

51. This option is explicitly dependent on international collaboration, and has been costed above on various assumptions as to the form of such arrangements. Even at this stage, some analysis is possible of the prospects for achieving appropriate co-operative arrangements.

52. An agreement with France reflecting the 1979 draft agreement could be quite wide-ranging, covering the fuel cycle as well as the basic reactor technology and could benefit the UK technologically. The 1979 draft agreement proposed collaborative links between the UKAEA and CEA; SERENA and a new UK fast reactor organization; and NPC and NOVATOME. With their relative lack of indigenous energy supplies, the French are more likely to press forward with a fast reactor programme than the Americans, despite the recent change of government in France.

53. The rate of progress and success of the Phenix and Super-Phenix 1 projects associated with the impossibility of a formal commitment by the UK to a CDFR project before 1986 could, however, militate against any very beneficial collaborative arrangements being reached with France particularly if the outcome of the negotiation were to result in keeping the UK in an inferior position with less than full access to technological information or full involvement in development projects, whilst requiring the UK to surrender the power to control independently the sale of its own technology to third parties. Another stumbling block would arise with continued French insistence on payment of an "entry fee" for access to the results of previous research, and of continuing payments at least until a UK CDFR is commissioned. However the French may modify their approach to these issues, in which case attainment of a mutually acceptable agreement could be feasible.

54. Collaboration with the USA has the advantages of joining with a partner on a more equal basis. Where the UK has a wealth of technical knowledge and expertise stemming largely from its long history of operating fast reactors (DFR and PFR) and fuel plants and its highly competent CDFR design team, the USA has concentrated on extensive development programmes that use large test facilities culminating in its recently operational Fast Flux Test Facility but no commercial fuel reprocessing experience. Thus in many ways the respective programmes complement one another and offer potential for achieving a good collaborative agreement on an equal partnership basis. The similarity of views of the two countries on the control of nuclear technology and non-proliferation issues should greatly assist in the formation of an agreement. Current programme timing also makes America attractive as a partner to the UK.

55. A major problem for the UK will undoubtedly lie in the considerable length of time that it will take to negotiate with the USA a firm agreement that includes a commitment to build demonstration plants. The greater uncertainty of stability of US

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government policy associated with the step-by-step approach to international agreements advocated by the US utilities create the risk that the UK may find the results of its extensive design, development and prototype reactor programmes passed to the USA without any final agreement to plant construction. Clearly, if no firm commitment is made early, the UK's negotiating position will be progressively weakened. Finally, collaboration with the USA raises the issues of source(s) of funding, particularly of capital, within the USA and of guarantees that agreements made by a complex US government-utility partnership will be maintained. A proper evaluation will only be possible in the light of firmer confirmation of American initiatives including their attitude to co-operation with the UK on a demonstration reactor project and fuel cycle facilities.

Collaboration negotiations will discuss the location of the first demonstration reactor (which has been assumed to be in the UK in the diagram). If this was built abroad, it is expected it would only delay slightly a similar total expenditure. However, the UK's readiness to deploy fast reactors commercially would be delayed.

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OPTION IV: EARLY COMMITMENT IN PRINCIPLE TO A UK PROJECT NOT NECESSARILY DEPENDENT ON INTERNATIONAL COLLABORATION

Outline

Early commitment to work towards UK CDFR

Willingness to seek international partners

Benefits

Acquisition of a commercial power station

Most certain way of securing fast reactor option in UK

Significant boost to nuclear industry

No licence fees

Costs and Risks

Expensive

Possibly not cost effective if no collaborators found

International Collaboration

Policy very attractive to potential overseas partners. This option could rapidly move towards Option III, with its attendant advantages.

Agreement with France or US possible on potentially the most favourable terms

Resource Implications

COST ESTIMATES FOR "GO-IT-ALONE" POLICY (£M at 30.9.81)

	82/83	83/84	84/85	85/86	86/87	87/88	88/89	93/98	98/2003	TOTAL
<u>Reactor and Fuel Plant Costs</u>										
Capital						30	1000	150		1270
Operations								50	100	150
<u>Fuel Plants: Capital</u>						3	158	149		310
<u>Operations</u>								112	138	250
<u>Sub-Total</u>						33	1248	461	238	1900
<u>Credit</u>										
PWR Capital						20	740	100		860
Operations (inc. Fuel)								165	275	440
<u>Total Credit</u>						20	740	265	275	1300
<u>Total Net Plant Costs</u>						13	508	196	-37	680
<u>Development and Endorsement Costs</u>										
AEA (Development)	52	54	57	56	70	67	247	112	85	800
MHC/Industry (Endorsement)	9	9	9	5	31	35	71	15	2	190
BNFL	-	-	-	-	5	15	49	20	16	110
PFR and Plants	47	40	36	35	37	38	151	16	-	400
<u>Total Development Costs</u>	108	103	102	105	143	155	518	163	103	1500

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IV Early commitment in principle to a UK project not necessarily dependent on international collaboration

(a) Outline

56. Under this option, the UK would commit herself to working towards construction of a CDFR and while seeking international co-operation accept the possibility, subject to review, of incurring the total expenditure involved in going-it-alone. The timescale would be similar to that assumed in paragraph 42 under Option III: Public Inquiry 1985/6; granting of a site licence on the basis of the safety report in 1986/7; construction to begin in 1987/8. Thus the speed of progress would be limited only by delays deriving from technical constraints and public policy matters such as a public inquiry.

57. However, any programme centred on a demonstration project on this major scale will necessarily be costly, and this applies with added force to projects representing the first-of-a-kind and involving high technology. It would be hoped, therefore, that the national commitment displayed by adoption of this course would serve to attract international collaborators on attractive terms. Thus although the initial commitment would be to pursue an independent project, this policy could be expected to merge into that of Option III as it progressed.

(b) Benefits

58. The benefits to the UK of adopting this policy are clear. Fast reactor technology would be developed to the commercial stage in time for the commercial series ordering to be embarked on by the earliest date. The design would be UK-based, and would be explicitly developed to provide an economical and proven reactor system satisfying UK safety policies. In addition, the domestic nuclear industry would have a more secure future, and the position of the UK among the leaders of nuclear technology would be confirmed. The likelihood of developing collaborative arrangements and markets with other nations would provide an added benefit.

(c) Costs and Risks

59. Clearly this option requires a considerable commitment of both finance and effort. These are difficult to quantify in detail in view of the likelihood that international collaboration would allow some cost reductions, through the sharing of process plants; the costs in this case could turn out to be of the same order as those outlined under Option III. However, the possibility would have to be accepted that no significant savings could be achieved from collaboration, and the costs of the policy assessed on that basis. The decision to incur these can be reviewed, before construction begins, in 1986.

60. The total cost, up to the year 2000, would involve net expenditure of £2180M, or £3480M gross less a PWR credit of £1300M. This option therefore involves a considerable capital investment starting in 5 or more years time, and will at the same time need a major manpower input, particularly skilled and experienced nuclear design and construction skills. These could be phased in to match the run-down in requirements for other projects such as the AGR programme and the THORP plant.

61. Undoubtedly, under this option, the UK could develop a fast reactor capability in time for any commercial need likely to arise assuming a stable world. However, given the costs to the UK entailed by this course, the major concern would be its cost-effectiveness. These might be of less concern when viewed against the possibility of unexpected political developments, involving major supply disruptions, which would improve the balance in favour of this option.

(d) International Collaboration

62. Going ahead on such a timescale with a full commitment to the project by Government would be highly likely to attract international collaborators. An agreement with France, again deriving from the 1979 draft agreement, could be very wide ranging, covering any or all of the whole field of fast reactor technology, and it is possible that the additional and public UK commitment could offset the problems with French collaboration outlined earlier. Collaboration with the US, under this programme, would be qualified with the same doubts as were outlined previously, with the added disadvantage that the US would initially be the junior partners.

63. Overall, a national commitment to a fast reactor programme on the lines indicated would place the UK in a very strong negotiating position, well positioned to extract significant benefits, both technical and financial, from international collaboration. In fact, although Option III has been formulated or is explicitly dependent on overseas collaboration, the chances of negotiating a cost-effective partnership would be greater with a clear commitment by the UK Government to proceed towards fast reactor commercialisation. Initial willingness to accept the total cost of going-it-alone could be the most effective way of achieving successful commercialisation at minimum cost through international collaboration.

"Additional Fast Reactor Policy Options"Timing and the nature of informed buyer status

1. If the UK is to abandon its independent capability and rely on buying overseas technology the implications for the timing of the introduction of the system are considerable. In these circumstances the UK cannot begin to introduce fast reactors until a fully demonstrated commercial system (i.e. reactors and full scale fuel plants) is available and on offer by an overseas supplier. Other countries could reach overall collaboration agreements and it is possible therefore that the UK would be faced with a monopoly cartel on fast reactor technology, especially if early ordering of commercial stations was desired. While licence fees would be subject to commercial considerations it could be difficult to resist onerous conditions related to political and manufacturing aspects of the fast reactor system.
2. The front runner to reach this position must be seen at this time as France. It is difficult to see such demonstrated technology, covering as it must the entire fuel cycle as well as the reactor, being available in the USA, Japan or Germany on a shorter time-scale - although the USA and/or Japan cannot be ruled out should a pressing need arise (unlikely in the US case in view of their indigenous uranium). Soviet technology has been discounted as a dependable future source. Taking the French programme it is judged that this will achieve a commercially demonstrated fast reactor system in the period 2015 to 2020. The timescale is likely to be dictated by the date at which commercial-sized economic fuel cycle plants are in operation.
3. The implications of this sort of timescale on the work and objectives of a "core team" are considerable and raise issues on the justification and feasibility for this type of strategy, particularly for the cases where the level of resources is below those likely to attract serious overseas interest (for example in our achieving some kind of junior partner status).
4. After licensing the timescale to commercial series ordering in the UK is also likely to be protracted. The following factors suggest a "lead" station will be necessary:

- (i) The technology will be of foreign origin and not necessarily acceptable to UK site licensing* or safety authorities.

*Because the word "licensing" can refer either to commercial activities or to safety consent procedures, this note uses the phrase "buying technology" rather than "taking a licence". Also a "commercial licence" is only part of the transactions which will require several licences plus the purchase of other services and of hardware.

- (ii) The economics require the reactor and its whole fuel cycle to be proved for UK use.
- (iii) The use of plutonium fuel involves issues of security and non-proliferation that go further than in the case of uranium-fuelled thermal reactors.
- (iv) Current experience on Sizewell PWR.
- (v) Even on a 2015 to 2020 scenario, the technology will be less proven than for Sizewell PWR.

With this assumption it would be a further 15-20 years from the date at which the technology is available before series ordering of fast reactors could begin, having regard for issues such as preparing for and holding the public inquiry, construction and operation of the "lead" reactor and proving the fuel cycle. Such substantial delays would impose economic penalties. The recommended CDFR route (Options III or IV) of course encompasses these stages earlier.

5. These timescales would require a start being made to build up the required industrial teams well in advance. The first stage of provision of advice to Government on the necessity to enter negotiations to buy technology could be provided by a relatively small core team, but the next stages leading to the taking of a licence and an NII evaluation and thence to the public inquiry are major, occur shortly after the decision, and without substantial expertise will involve costly delays. Skilled teams will be required in NNC/Industry, CEGB, BNFL, NII and UKAEA amounting to many hundreds of people.

6. By the time of the decision the UK nuclear programme should have grown giving the industry greater experience in thermal reactor construction but there is likely to be little innovative expertise on reactors and probably little on reprocessing since the latter in the absence of a fast reactor programme is likely to be severely restricted unless pressure before then has resulted in substantial recycle of plutonium in thermal reactors. Only some of the experience of thermal systems with minimal development or new design requirements will be applicable to fast reactor power stations and the associated fuel plants. There will be many requirements but in particular it will be necessary to assess designs for conformity with UK operating and safety requirements and possibly propose modifications; and to prepare cost estimates under UK conditions.

7. Experience with the Sizewell B PWR has been salutary. Although there are now some 100 PWRs operating worldwide, the CEGB through the Task Force found the reference design did not meet its safety or cost requirements, and two redesigns were necessary; the fast reactor case will be much more complex. Accordingly, very detailed independent safety assessments will be required in the preparation of the utility pre-construction safety report. In particular, as in the case of the PWR, the seller's safety codes will need to be checked. Given the limited

generic information passed across with licences this will require the buildup of considerable information and expertise.

8. In considering the pre-construction safety report the NII will seek evidence that fast reactors and the fuel cycle can be operated safely, under UK safety licensing conditions and not those of the selling country, which may differ considerably in philosophy and application. They may also seek design modifications. NII will require background technical support. Also at the public inquiry there will be a need to demonstrate that the UK has sufficient experience and expertise to cope with all the problems (both safety related and political) and including those of dealing with plutonium. Against this background it will clearly be necessary to re-establish some of the current range of fast reactor experimental facilities in the UK.

Programmes

9. It is against the above background that the following programmes describing what could be done for settled down expenditure of £50M, £25M and £10M p.a. (these have been termed Options II(a), I(b) and I(a)) need to be considered*. As stated earlier there will be requirements for the organisations which will be the buyers and users of imported technology - the Generating Boards, NNC, BNFL, manufacturing industry and NII. For the purposes of this note the range of illustrative expenditures have been taken as covering essentially a core team in the AEA with, where appropriate, a modest allowance for expenditures for collaborative experiments overseas.

*In these cases where the Dounreay establishment would have to be placed on a care and maintenance basis as in Option 1, the £5M p.a. expenditure on the site is assumed to be additional to the work programmes outlined.

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Option II(a) Indefinite Delay with Maintenance of Minimum Programme at £50M pa
Settled Down"

Timeline

Essentially Option II

to operate up to early/mid 1990s

ward programme reduced and orientated to generic and safety issues

Maintenance of informed buyer status

structured programme not involving large plants in late 1990s

Benefits

Significant reduction in expenditure

Maintenance of UK position as informed buyer

Maintenance of some fast reactor expertise

Maintenance of Dounreay

Costs and Risks

Necessity to review programme again in late 1980s

Loss of design expertise and industrial prospects

Loss of demonstration step leading to delayed ability to adopt FR

Significant staff displacements in all organisations at a time when other workloads tending to decrease

International Collaboration

Little chance of significant collaboration on commercial development

Possible R&D contribution to major overseas programme (minor partnership in limited areas)

Necessity to license overseas technology

Resource Implications

	82/83	83/83	83/85	85/86	86/87	87/88	88/93	93/98	)
Operational (net)	36	29	25	22	19	18	61)		)
abrication and							)		)
trification			1	3	6	10	40)	110	)
plants (Capital)							)		)
hire/reprocess	11	11	10	10	12	10	50)		)
Development/Safety:									)
	52	42	35	30	29	28	149)		)
	9	1					)	140	)
		1	1	1	1	1	5)		)
PLS (Option II)	108	84	72	66	68	69	305	(250)	)
ductions from Option II									)
achieve Option II(a)	-	-	1	3	7	11	55	-	)
PLS (OptionII(a))	108	84	71	63	61	58	250	250	)

Continue
at £50M
pa.

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10. A fast reactor programme expenditure of £50M p.a. "settled down" is close to Option II and would be used to maintain the Dounreay plants in operation for at least the early years. Benefits and risks are thus similar to those made for Option II in AEA(82)32. Briefly this option can be seen as buying time, thereby enabling UK policy to be reviewed at any time over the next decade. One alternative could be to move back to planned construction of a CDFR (Option III or IV) but with costly delays compared with immediate adoption of that policy. Another alternative would be to run down the programme completely (Option I). Finally there remains the option of continuing with some form of fast reactor development until the decision was taken to construct a demonstration plant under licence. If expenditure is to be held at the £50M p.a. level it would not be possible to replace the plants at Dounreay and consequently a continued programme of this size would only make sense in some limited form of overseas collaboration with a country that has a strong plant development and construction programme. Whether a worthwhile deal of this kind could be made is uncertain.
11. Option II provided for continued operation of the Dounreay site and its plants with provision for expert support teams of minimum viable size at other AEA establishments and "settled down" to an expenditure of about £60M p.a. by the late 1980s. Reduction to £50M p.a. by this date will only be achieved with difficulty and will involve the loss of some areas of expertise.
12. After shutdown of PFR and its associated fuel plants, even allowing for some time and effort directed towards the early stages of decommissioning, substantial restructuring of the programme will be required. In the context of a limited association with an overseas country the UK could offer to contribute a useful R & D input. A considerable level of experimental work could be retained at the Dounreay site permitting it to undertake studies directed to, say, plutonium fuel plants and sodium engineering. Other AEA establishments could make contributions on safety, engineering and materials.
13. Despite the magnitude of the £50M programme there would still be substantial effects on Dounreay. In the short term the effects would broadly be the same as identified in Option II. Closure of the plants and a move to an experimental programme would have further severe social and economic impacts on Caithness. The high proportion of the semi-skilled and unskilled process staff associated with the plants would be redundant to requirements in an experimentally-oriented site - a rough estimate indicates that less than half the present numbers of non-scientists (~2000) would be required.

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Option I(b): Indefinite Delay with Maintenance of Minimum Programme at £25M pa "Settled Down"

Outline

Option I expenditure with addition of a modest R&D programme
 FR closed down and spent fuel reprocessed
 Dounreay site probably reduced to care and maintenance basis

Benefits

Substantial reduction in expenditure
 Maintenance of UK position as an informed buyer
 Maintenance of a limited fast reactor expertise.

Costs and Risks

Serious damage to UK's ability to introduce fast reactors when necessary
 Introduction would then take a long time
 Prospects for thermal reprocessing possibly damaged
 Continued responsibility for Dounreay site
 Dire consequences for Caithness area
 Significant staffing problems
 Questionable "value for money" programme

International Collaboration

No prospect of commercial collaboration: potential for some specialist R&D collaboration
 Necessity to licence overseas technology
 Danger of technology being unavailable or politically unacceptable
 Reduced UK influence on world use of plutonium

Resource Implications

COST ESTIMATES FOR UK POLICY OF MAINTENANCE OF £25M pa PROGRAMME (£M at 30.9.81)

	82/83	83/84	84/85	85/86	86/87	87/88	88/93	93/98	98/2003	
AEA:										
Dounreay	55	42	35	28	22	17	30	25	25	Continue at £(5+25)M pa
Refrification	44	27	2	5	7	14	23	125	125	
Other sites	9	1	25	25	25	25	125	125	125	
TOTAL	108	70	62	58	54	56	178	150	150	

It is stated that Option I(b) treated as retention of a £25M pa programme implies acceptance of Option I with an additional expenditure of £25M pa at AEA establishments outside Dounreay. The "settled down" cost of the development programme is reached by 1984 and is concealed by continuing work in bringing Dounreay to a care and maintenance state.

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14. With limits on "settled down" expenditure of £25M p.a. it will be necessary to shut down PFR and its associated fuel plants and therefore this Option is akin to Option I. In principle however it might be feasible to achieve a small alleviation of the dire consequences for Dounreay and Caithness by maintaining a limited level of development work at Dounreay as a component of a £25M programme. There would however still be an incentive to continue development work at other AEA establishments where there are well established centres of expertise. For example location of the continuing safety and safety oriented studies at AEE Winfrith could not be readily transferred to Dounreay. The high cost would militate against this even if the qualified staff could be transferred. The numbers that could reasonably be retained at DNE would amount to about 100 professionals (about one-third of the current level). This would be a contrived policy and would not be cost effective; the Dounreay site would have to be maintained with all the facilities such as engineering workshops, analytical laboratories, administrative support, that are required to support a development team even although the team is small. Consequently the overheads would be high leading to a high tariff for any work undertaken. It is also reasonable to assume that some new capital facilities would have to be provided. Even if an experimental programme were to be maintained at Dounreay, there would be a substantial social and economic impact on Caithness resulting from redundancies of large numbers (about 1400) semi-skilled and unskilled staff. This arises because of the much lower demand for such labour on an experimental site as against one that has large operating plants.

15. It is likely that under this Option the Dounreay site would be reduced to a care and maintenance basis but with the provision of some resources to support a modest fast reactor programme at AEA establishments outside Dounreay. Against the background of the earlier remarks about timing, a programme at this level could be expected to continue for about 30 years, and the content and purpose would need careful consideration.

16. A programme expenditure of £25M p.a. would fund reasonable R & D resources (about half those allocated for the current CDFR development programme). With the shut down of PFR and the fuel plants and the effective closure of Dounreay restructuring of the remaining programme (in addition to reduction) would be required, and this would have to be in the direction of a more generic safety and development approach - particularly as the fuel irradiation and plant development aspects would be severely curtailed. However, rather than spend this level of expenditure on generic work alone it would be preferable to attempt to arrange at an appropriate juncture to contribute the limited development programme to an overseas one in return for some future preferential supply terms although it is not likely that this will be an attractive proposition. Otherwise the programmes would focus on safety and safety related work, experimental work on fuel performance, fuel plant development and reactor engineering making use of existing facilities both in the UK and possibly overseas (e.g. irradiations in overseas reactors). A substantial involvement in overseas experiments could form a significant component of the programme and could extend to attachments of UK staff.

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Option I(a): Indefinite Delay with Maintenance of Minimum Programme at £10M pa "Settled Down"

Outline

Essentially Option I but with retention of small generic programme
 Closed down and spent fuel reprocessed
 Dounreay site reduced to care and maintenance basis
 Forward programme reduced and oriented to generic and safety issues
 Maintenance of watching brief on international technology

Benefits

Major costs of commercial fast reactor development deferred (although savings would be in the medium term rather than immediate, and perhaps negative overall if fast reactors were ultimately required)

Retention of very restricted technical capability

Costs and Risks

Serious damage to UK's ability to introduce fast reactors when necessary

Introduction would then take a long time

Prospects for thermal reprocessing possibly damaged

Continued responsibility for Dounreay site

Dire consequences for Caithness area

Significant staffing problems

International Collaboration

Prospect of commercial collaboration: slight possibility of limited R&D exchanges
 Necessity to licence overseas technology
 Danger of technology being unavailable or politically unacceptable
 Reduced UK influence on world use of plutonium

Resource Implications

ESTIMATES FOR UK POLICY OF MAINTENANCE OF £10M pa PROGRAMME: (£M at 30.9.81)

	82/83	83/84	84/85	85/86	86/87	87/88	88/93	93/98	98/2003	
AEA:										
Dounreay										
Plutonium										
Other sites										
MC:										
TOTAL										
	55	42	35	28	22	17	30	25	25	Continue at £(5+10)M pa
	44	27	2	5	7	14	23			
	9	1	16	10	10	10	50	50	50	
	108	70	53	43	39	41	103	75	75	

that Option I(a) treated as retention of a £10M pa programme implies acceptance of Option I with an additional expenditure of £10M pa at AEA establishments outside Dounreay. The "settled down" cost of the development programme is reached by 1985 and is concealed by continuing work in bringing Dounreay to a care and maintenance state.

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17. With limits on "settled down" expenditure of £10M p.a. it will be necessary to shut down PFR and its associated fuel plants and to cease effectively all operations at Dounreay. This low expenditure programme is therefore essentially a variation on Option I but with the provision of some resources to support a limited generic research programme. Against the background of the earlier remarks about timing, expenditure at these levels could be expected to continue for up to 30 years, and the content and purpose of associated long term programmes therefore need careful consideration.

18. For an expenditure of £10M p.a. the retained team would comprise a total of around 100 professional staff who would be largely deployed on safety work and related topics such as reactor fuel performance, assessment, materials properties and structural integrity together with a small deployment on longer term possibilities in fuel fabrication and reprocessing technology. This virtual elimination of the fast reactor programme would result in major changes in the UKAEA and its facilities. Concentration on these areas would recognise the need for the UK, when it decides to embark on a fast reactor programme, to have some capability to undertake independent safety assessments and to assess its requirements for fuel fabrication and reprocessing plants. It must be emphasised that only a limited amount of experimental work will be possible with such a small team and much of the effort will be devoted to studies of overseas literature and general assessments. Limited participation in one or two overseas experimental projects could be possible.

General

Impact on the Authority and on Caithness

19. If a decision were taken to move to either the £10M or £25M programmes, the Dounreay establishment would have to be reduced to a care and maintenance basis. This would give rise to profound effects both on the Authority and on the Caithness region.

20. The £50M programme would also have a significant impact on the Authority and large numbers of staff both at Dounreay and at the Northern Division Laboratories would be displaced and one or more of these latter might need to be closed. The following table gives an indication of staff displacements, and of possible redundancy (where appropriate) and other staff displacement and relocation costs for all three programmes. There would also be staff displacements at BNFL and NNC.

	Staff Displacements	Redundancy, Relocation and Reallocation Costs £M					
		83/4	84/5	85/6	86/7	87/8	88/93
II(a)	1900-2100	7	11	10	13	12	39
I(b)	3100-3300	14	31	9	11	12	38
I(a)	3800-4000	17	43	13	14	16	49

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21. By 1990 without any emigration job losses in Caithness could amount to 2800 and result in total unemployment of 33%. In practice there will be some emigration, leading to further job losses in the local services sector and more rapid rundown in the prosperity of the district.

16th August 1982

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FAST REACTOR - SCOPE FOR INTERNATIONAL COLLABORATION

Introduction

1. The UK has had separate discussions with the French and with the Americans over the last fifteen months. This note describes the latest position reached with each country, and comments on future prospects. By way of additional background a note describing the stage which fast reactor development has reached in these and other countries is at Appendix C1.

2. Positive progress has been made with both sides. The UK has had an exchange with each country on basic principles which might underlie a collaboration agreement based on our proceeding towards a CDFR with a programme maintained at around the present level. These exchanges have established that there is the potential for a satisfactory collaborative deal with either country. But detailed industry level negotiations which are now in train with each country, will be needed to establish the precise terms we could secure.

Principles

3. The UK principles on which our discussions have been based envisage the following desirable features

- (i) A long term collaborative arrangement, extending through to the commercialisation phase
- (ii) A wide and exclusive agreement covering fast reactor and associated fuel cycle facilities, with objectives of
 - (a) co-ordinating R&D
 - (b) minimising duplication
 - (c) advancing fast reactor technology to state where it is a demonstrated option
 - (d) evolution of a basic design concept to meet the expected requirements of utilities when they require numbers of fast reactors
 - (e) encouraging collaboration at all levels including at the supply end, possibly by cross-investment

Detailed arrangements to be negotiated at industry level.

- (iii) arrangements to control exploitation of fast reactors/fuel cycle information and technology deriving from the co-ordinated programme
- (iv) Extension to 3rd countries (eg Japan) by mutual agreement
- (v) arrangements safeguarding material and information to ensure peaceful purposes are served.

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Discussions to date

4. Discussions have revealed a broad measure of understanding with both sides. Both the European and the Americans recognise the UK's achievements and expertise and there is broad agreement on the desirability of a long-term collaborative agreement; each country also recognises the potential benefits to be derived from a co-ordinated approach to R&D and the concept of joint design work to minimise costs and advance the date when the fast reactor is a commercial option. There is agreement on non-proliferation aspects.

5. The position of each country is described in more detail below.

Discussions with French

6. The Mitterand Administration has moved away from the position adopted by its predecessor in 1979, when the UK was in effect only offered a licensing arrangement rather than collaboration. French Ministers have made it clear they attach political importance to an agreement with the UK. The French have not only conceded that we should explore the possibilities for a relationship between UK industry and the Franco/German partnership which would be equivalent to membership of the partnership and is a key to genuine collaboration. They have also dropped the 1979 proposal that the UK should pay a £50m entry fee.

7. However, there are some features in the discussions which have not so far been resolved. In particular whilst the French are prepared to offer the UK an equal stake alongside themselves as the ultimate goal of an expanded collaboration they presently appear to envisage only limited R&D co-operation until the UK announces a policy of proceeding towards construction of CDFR. At this stage of the industry-level negotiations it cannot be judged whether a progressive approach to collaboration will offer the UK any real benefits and scope for worthwhile cost savings. There may also be some risk that the French might seek to use collaboration as a means of getting the UK to accept a design based on Super Phenix technology, which may not necessarily be acceptable.

8. However, genuine collaboration on design work - if they and their partners are prepared to agree with this in industry-level negotiations would be very valuable especially as the French are now world leaders in development of fast reactors.

Discussions with the Americans

9. An agreed statement of mutual views has been reached with the Americans which reflects closely the principles in 3 above, and is evidence of the Reagan Administration's positive interest in the idea of collaboration. As Appendix C1 indicates the Americans currently lag behind Europe in the fast reactor development. But despite the Administration's continuing problems in getting its Clinch River Breeder (equivalent of PFR) constructed they are now planning the next stage of development. \$15m is earmarked in the current Federal budget for initial funding of an international collaborative effort to design a commercial demonstration reactor.

10. At this stage it appears that the US option offers scope for genuine collaboration on reactor design; without early pressure to move towards construction of a CDFR. On the fuel cycle side the UK enjoys an even greater lead over the Americans and it is conceivable that ab initio they might be prepared to pay for use of the Dounreay reprocessing facility rather than build their own, though this may be difficult to negotiate and bring about. Subject to any overriding political constraints this could be an attractive proposition.

11. The main problems encountered with the Americans are, firstly, their attitude to exclusivity (i.e. the challenge of harnessing a large number of private sector manufacturers, utilities and Government agencies to a single collaborative agreement with the UK, which could only be extended to third countries by mutual agreement), and secondly, the timing of industry-level negotiations. Despite the preference formally expressed to the Administration by a large part of American utility industry in favour of collaboration with the UK, the Administration sees legal philosophical and institutional difficulties in committing the US to an exclusive co-operation with the UK or anyone else. However they believe that if we have a successful collaboration it will in practice be exclusive, and the Administration are ready to work towards this. But the degree to which we can get a sufficiently committed agreement with the US utility industry and with the reactor industry is not yet clear.

12. Because of these institutional problems, and also the Americans desire to involve the Japanese in bilateral discussions about collaboration, and their relatively relaxed timescale for construction of a commercial scale plant, it is likely that industry-level negotiations will be relatively protracted. It could take several months or longer before a specific collaborative framework is identified and perhaps up to two years before detailed commitments can be made.

Summary

13. In both countries there is the political will to have an agreement with the UK. But it is still too early to attempt a quantitative, or even fully considered qualitative, assessment of the respective European and American collaborative options, though industry-level negotiations are continuing with each country. Prima facie the prospects for an early agreement seem better with the Europeans, though the UK might have to accept the role of a relatively junior partner unless and until it had announced a policy of proceeding towards the construction of CDFR. Indeed a phasing back of the UK programme, of the sort envisaged in the main paper would change both the nature and tempo of negotiations. There may be scope for a more closely integrated collaborative programme with the Americans, but exclusivity and timing pose problems which may not easily be resolved.

THE STATUS OF THE FAST REACTOR WORLDWIDE

(Summary)

Prototype fast reactor power stations are now operating in the UK (PFR, since 1974), France (Phenix, since 1974) and the USSR (BN 350, since 1973; BN 600 since 1980). There are test reactors in operation in the USA, France, Germany, Japan and the USSR: and two more are currently being built in Italy and India.

Although France started to develop fast reactors later than the USA, USSR and UK, a consistent and determined programme over the last 15 years has placed her ahead in the commercialisation of fast reactors in the West. And when, as seems probable, the commercial scale Super Phenix I (1240 MWe) reaches high power in 1984, she may then also be judged to be in advance of the USSR. Construction of Super Phenix I at Creys-Malville near Lyons is two-thirds complete, many of the large items of plant having been installed within the time originally scheduled.

The very successful operation of Phenix since 1974 (e.g. 63% load factor 1974-1981; 80% from 1978-1981) can be traced to the earlier thorough testing of fuel pins and reactor components and to the use of well-tried conventional steam circuits. The test reactor Rapsodie has provided since 1967 a main irradiation vehicle for fuel pin testing and development.

The commercial demonstration pool-type reactor BN 600 at Beloyarsk reached 80% of its full power (1470MWt) during 1980 and produced over 10^9 KW hour (= 70 EFPD) by the end of that year. Commissioning experience was good but at least two small leaks in steam raising modules occurred in 1980. (There are 72 steam raising modules with some excess capacity, so that the disconnection of two does not affect the electrical output attainable). The prototype loop-type BN 350 at Shevchenko has run very reliably at 650-700 MW (about $2/3$ nominal full power) for the last few years, producing 125 MWe and up to 80,000 tonnes of distilled water per day.

While the USA has probably the largest and most comprehensive R & D programme of any country, the plans and timing for commercialisation of LMFBRs are uncertain. Current US DOE projects include the Fast Flux Test Facility (FFTF), the Clinch River Breeder Reactor (CRBR) Plant, and the Conceptual Design Study (CDS) Large Development Plant.

The FFTF, specifically designed for development and testing of fast breeder reactor fuels and components, achieved full power (400 MWt) in December 1980, following a successful commissioning programme which included natural convection cooling tests for shut-down from full power.

The design of the 375 MWe CRBR is nearly complete. About £60M worth of components, including the reactor vessel and a prototype steam generator, have been delivered. Another £100M is currently being spent on components and the total for all contracts already placed for components is £275M.

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Following earlier delays caused by a system of part-licences, a law-suit and political problems, there has been some small improvement in the support for the Federal Republic of Germany's SNR 300 and safety permission has been given for the next two years of construction. However, the cost over-runs are causing some concern, particularly to Belgium and Holland. At present 80% of the components for SNR 300 are complete. There will be no decision on the commercial scale SNR 2 before SNR 300 operation (in 1986?) although some preliminary design studies are complete. Since start-up in 1979, good progress has been made with the fast test reactor KNK II (20 MWe). Fuel burn-up has reached 4%. Two failed pins have been detected and removed from the core.

Japan like France relies almost entirely on imported fuel and therefore has an urgent need for commercial fast reactors. Much of the development work in the 1970s centred upon the experimental fast reactor JOYO which ran at 75 MWt for part of 1980, accumulating 4×10^5 MW hour heat output and taking fuel to 2-3% burnup. The design of a 300 MWe prototype (MONJU) is virtually complete. A site for MONJU has been found near the LWR station in the Tsuruga Peninsula, 400 km west of Tokyo. The licensing procedures for start of construction are "being intensively conducted". A preliminary study for a 1000 MWe loop-type demonstration reactor to follow MONJU has been published, with a start of construction envisaged for about 1990.

Progress with the Italian 130 MWt test reactor PEC has been slow (the civil work is 60% complete), but some progress with licensing part of the plant has been made. More part-licences are expected during 1981.

India is building a test reactor (FBTR) at Kalpakkam, which is similar to Rapsodie (except that it includes steam generators) with help from France. Work is 95% complete and commissioning is expected in 1982/83.

Approximate Comparison of Annual Expenditure on, and Manpower Devoted to, Fast Reactors

(1981)

<u>Country</u>	<u>Expenditure £M/year</u>	<u>Professional Manpower</u>
USA	300	1500 +
France (a)	165	1500 (c)
UK (b)	110	600
Japan	105	500 (d)
Italy (a)	90	-
DEBENE (a)	80	1100
India (e)	7	400
TOTAL	857	5600

NOTES:

- (a) Includes contributions to NERSA for Super Phenix
- (b) Includes UKAEA and NNC only
- (c) CEA only; excludes EdF
- (d) PNC only
- (e) Kalpakkam Reactor Research Centre only (the main centre for fast reactors)

3rd August 1982

ATTITUDE OF THE AEA AND OTHER INTERESTED BODIES

Apart from the detailed advice submitted by the AEA on the options which is appended to Annex B of the main paper, a shorter statement of their position together with the views of the other interested bodies follows

The AEA

2. The Authority's economic analysis (annex A of the main paper) shows that a CDFR with its first of a kind costs, started in the eighties, using a small scale fuel plant is unlikely to be competitive with expected PWR generating costs, but could compete with coal over its lifetime and could approach AGR costs. However the Authority believe that the benefits of replication, learning, full utilisation of economic sized fuel plants, and the upward movement of world uranium is likely to reverse the PWR comparison in due course. They believe that the breakeven is likely to occur with stations commissioned between 2010 and 2020.

3. The AEA strongly favour Option III. A programme which includes a full scale demonstration reactor would provide the best assurance of having the fast reactor option available when required but it would not be necessary to decide now on the best timing of the demonstration reactor. Arising from the discussions with organisations in the US, France, Germany, the Authority do not consider that it will be possible to get a worthwhile collaboration agreement with other countries unless the UK itself has intent to build a full scale demonstration reactor, but an agreement when reached on this basis should then give some flexibility on timing and perhaps allow a lower spend than given in Annex B. . Choice of Option III does not itself require any commitment for 5 years or more to new or increased financial expenditure. The final decision to build CDFR could not be taken for several years. The alternative of adopting Option II or IIa means a substantial rundown with the loss of much UK fast reactor expertise, the probability of exclusion from a long collaboration arrangement between the US, Europe and Japan, and of will delay in the availability of the fast reactor option. It will also require further decisions in about 10 years time, but Option II cannot be regarded as a holding action which would enable Option III to be adopted later. The interim loss of assets and negotiating position could not be recovered.

4. The moderate short-term savings implicit in choosing Option I, Ia or Ib must be seen against an irreversible loss of the UK's ability to retain an option to use fast reactors as a major, secure, source of power for the next 50 years.

CEGB's Views

CEGB consider that there may be a need to start commissioning commercial plants from about 2015; but they regard the uncertainties as such that it could be some years earlier or decades later. They also endorse the AEA's recommendation of option III. They say that if a decision were taken to proceed with an early CDFR, the Board could not be expected to provide other than a token contribution to the construction of the plant. If however a start of the CDFR were delayed until well after 1990, and was based on considerably greater development experience than we now have, the Boards financial

participation in the construction could be substantial, with an upper limit of the cost of a PWR of equivalent capacity. The CEGB would not at this stage reject the concept of licensing (ie options I and II) or even international collaboration as a junior partner based on a curtailed UK programme (ie option II or IIa)

SSEB's Views

6. SSEB agree that on present estimates of supply and demand fast reactors will be required commercially in the early part of next century. They consider that in view of the time needed to bring the new system to the point of full commercial application this means starting now with the appropriate steps to follow operation of the PFR at Dounreay. They see strong arguments in favour of siting a CDFR at Dounreay, and would not rule out the possibility of making a financial contribution to the project

NNC's Views

7. The NNC who are developing the design for the CDFR consider the fast reactor and fuel cycle based on today's technology as unlikely to be competitive with thermal reactors for another 40 years, and this only after construction of several uneconomic plants. They favour expenditure directed more towards new concepts which might produce a competitive fast reactor-system rather earlier, and consider that this could be more effectively and economically done in an international collaboration. They believe that a viable UK fast reactor development programme leading to construction of a CDFR could be sustained for around £50m per annum, and that this could provide a basis for some form of co-operation with other countries. They might be willing to contribute £1m pa to a programme provided there was a firm Government commitment and a declared objective, and provided NNC would have a voice in formulation of the programme, in any collaborative proposals, and in the management of any joint bodies.

BNFL's Views

8. BNFL's assessment is that earliest introduction of the fast reactor would be between 2015 - 2020. They believe that a fast reactor programme should be continued; but on a collaborative basis, and one that really saves money. They would be prepared to contribute financially and would not rule out the possibility of the company devoting a few per cent of its profits to support fast reactor fuel cycle work - ie say £10 - £20m over the next ten years.